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A RISK AND COMPARATIVE ANALYSIS OF AIRCRAFT ACCIDENT DATA

James Michael Burin

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A RISK AND COMPARATIVE ANALYSIS OF AIRCRAFT ACCIDENT DATA

by

James Michael Burin

September 1974

Thesis Advisor: R. A. Stephan

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two factors, the exposure to the risk areas and the performance in them, which were used to construct a risk measure and to explain the differences in the present accident rates. A procedure to predict risk was developed. A statistic, improvement index, was developed to allow a direct comparison between different types of aircraft with respect to safety performance with differences in risk taken into account. Another statistic, weighted improvement index, is proposed to provide insight into where the primary positive and negative contributions to Naval aviation safety are made in any given year. The aircraft studied were the major Naval operational and training aircraft, and the period of primary interest was fiscal year 1969 through fiscal year 1973.

A Risk and Comparative Analysis
of
Aircraft Accident Data

by

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Submitted in partial fulfillment of the
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ABSTRACT

Aircraft accident data was analyzed to investigate the differences in risk of Naval aircraft and to develop some overall risk measure. To analyze risk, a flight was divided into four risk areas; takeoff, inflight, transistion, and landing. Accidents were assumed to occur according to a Poisson process and tests were carried out to prove the validity of the Poisson assumption. The Poisson model yielded two factors, the exposure to the risk areas and the performance in them, which were used to construct a risk measure and to explain the differences in the present accident rates. A procedure to predict risk was developed. A statistic, improvement index, was developed to allow a direct comparison between different types of aircraft with respect to safety performance with differences in risk taken into account. Another statistic, weighted improvement index, is proposed to provide insight into where the primary positive and negative contributions to Naval aviation safety are made in any given year. The aircraft studied were the major Naval operational and training aircraft, and the period of primary interest was fiscal year 1969 through fiscal year 1973.

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TABLE OF SYMBOLS AND DEFINITIONS

Aircraft Studied	Description
A-3	Twin engine, multi-crew jet aircraft. Primary mission of tanking and electronic warfare.
A-4	Single engine, single or dual crew jet aircraft. Primary mission of training and attack.
A-5	Dual engine, dual crew supersonic jet aircraft. Primary mission of recconnissance.
A-6	Dual engine, dual crew jet aircraft. Primary mission of attack.
A-7	Single engine, single pilot jet aircraft. Primary mission of attack.
F-4	Dual engine, dual crew supersonic jet aircraft. Primary mission of fighter and interceptor.
F-8	Single engine, single pilot supersonic jet aircraft. Primary mission of fighter and interceptor.
E-2	Dual engine, multi-crew turboprop aircraft. Primary mission of airborne early warning.
P-3	Multi-engine, multi-crew turboprop aircraft. Primary mission of anti-submarine warfare.
S-2	Dual engine, multi-crew prop aircraft. Primary missions of anti-submarine warfare, training, and logistics.
T-28	Single engine, single or dual crew prop aircraft. Primary mission of training.
T-2	Dual engine, single or dual crew jet aircraft. Primary mission of training.

F-14	Dual engine, dual crew supersonic jet aircraft. Primary mission of fighter and interceptor.

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I. RISK ANALYSIS

A. INTRODUCTION

The present Naval aircraft accident rate (average number of accidents per 10,000 flight hours) accounts for all risks an aircraft faces during a flight. However, this rate implies that the accident rate is the same for every hour of flight. For example, if the accident rate for an aircraft is 1.0, this implies that the accident rate for every flight hour is .0001. This implication is not true because some phases of flight are inherently more dangerous than others. With this fact in mind, what is a good measure of risk for an aircraft. In other words, does there exist some combination of aircraft accident data which is a valid measure of overall risk? Since a flight is made up of many risks, it seems reasonable to first look at risk by components and then combine these in some manner for an overall risk measure rather than trying to evaluate all risks at once. Therefore to gain more insight into the analysis of risk, a flight was first divided into four risk phases; takeoff, inflight, transistion, and landing. These phases were defined according to Naval Safety Center accident code definitions as follows: takeoff was defined as the time from the start of takeoff roll until the aircraft is in a climb configuration and climbing; transistion is a combination of the time from start of climb until reaching a cruise altitude and the time from leaving a cruise altitude until in the landing configuration;

landing is the time for initially in the landing configuration until the completion of the landing roll; inflight is that portion of the flight after the climb and before the descent to land. These four areas were used to help find an overall risk measure for an aircraft, or in other words, a risk index. One application of this index could be to more quantitatively explain why aircraft accident rates differ.

B. BACKGROUND AND THEORY

To evaluate risk, what was needed was some method to analyze aircraft accidents in an analytical framework. Because the occurrence of an aircraft accident can be considered to be an event in an accident counting process, a Poisson approach to the problem of accident modeling and risk analysis was used. Statistical tests were initially carried out to determine if all aircraft accidents over a year's period of time form a Poisson process. Tests were also done to determine if accidents by specific types of aircraft and by different risk areas can be considered Poisson processes. The Poisson property of independent increments was assumed within each risk area. It can easily be shown that the exponential inter-arrival times and memoryless properties of the Poisson process are inherent by the nature of aircraft accidents. A final Poisson property that was used is that given n accidents in a period of time t, these n accidents will be uniformly distributed over t. This property was used in the statistical tests that the accident

process was of the Poisson type. The results of the tests confirmed the Poisson assumption of aircraft accidents in every case investigated (Appendix A), Because of these results and assumptions, all aircraft accidents were assumed to follow a Poisson process.

The Poisson approach represents an analytical modeling tool that can be used in the evaluation of all accidents to determine a risk measure. Now that this model is available, what would be the best way to use it to develop a risk index? First, using the Poisson assumption and also using the reproductive property of the Poisson process, the division of a flight into risk areas is now analytically possible. Using a Poisson model, the accident rates in each of the four risk areas represent, in a reproductive manner, the total accident rate. In effect, this approach modeled aircraft accidents as an inhomogeneous Poisson process by allowing for different accident rates in the different phases of flight. These accident rates for each risk area are called risk rates. The risk rates reflect the safety performance of an aircraft in any given risk area of a flight. Since total risk is a combination of many risks, it would seem reasonable that the first step in developing a risk index should be the computation of the risk rates. By evaluating the risk in the defined areas much insight into the breakdown of total risk can be obtained. Once risk in the risk areas has been evaluated, it is evident that some combination of the four risk rates will give the total

risk measure desired. The exact combination of these risk rates to use to get the most valid risk index is dependent on the approach used. One approach would be to add together the risk rates over the four risk areas for a given aircraft to obtain a risk index. However, the risk index obtained in this manner does not account for the proportion of flight time spent in each of the risk areas. Thus it seems a better approach would be to use some weighting factor for each risk rate to appropriately weight it in terms of the contribution of each risk area to the total risk. The best weighting factor becomes obvious when we realize that our analytical model is a Poisson model, and as with a normal Poisson process another factor beside the performance (risk rate) in a risk area which is accounted for is the exposure to risk. This is needed to give some idea of how much an aircraft is exposed to each of the risks considered. To perform a complete risk analysis using our Poisson model, the exposure and the performance should both be utilized in some manner in the development and validation of a risk index for any aircraft. With this and our weighting factor in mind, the immediate candidate for a risk index is the present accident rate. It has the properties required of a risk index in that it accounts for all risks an aircraft faces and the exposure to these risks. Because of this fact, it would seem to be the best measure of *total* risk faced by an aircraft. The accounting for of total risk by the accident rate is also a valid concept because of the reproductive property of the

Poisson process. No matter how many contributions, in the sense of risk, the present rate has, the total of these individual risks will be realized in the present accident rate. These specific risks could include the four areas already used, plus factors such as single engine risk, single pilot risk, day/night risk, pilot experience level, pilot proficiency level, and many others. The reproductive property is demonstrated by realizing that for any aircraft, the sum over the four risk areas of the risk rate multiplied by the exposure to risk, in percent of flight time, is equal to the present accident rate for that aircraft. This property, the total accounting for of the performance and exposure in each risk area, is exactly what was desired of a risk index.

The approach of using the accident rate as a risk index assumes that for a risk to be classified as such, it must be realized in the form of an accident. In other words, if no accidents occur in a risk area, the risk rate will be zero. A reasonable alternative to this approach would be a Bayesian approach for determining the risk index of an aircraft. However, it is felt that the priors, which would allow a personal input of risk evaluation, would be too subjective to yield valid results. Also, another reason the accident rate is superior to a Bayesian type risk index is that when a risk changes, the accident rate will automatically reflect the change in risk while the Bayesian approach would have to account for the change in other, more subtle ways. Granted, over a short period of time the accident rate may

not be a true measure of risk because the true performance in a risk area may not be realized due to limited exposure. However, over a long period of time, for instance more than 20,000 flight hours, the exposure will be sufficient so that the accident rate will essentially approach "steady state". As an example of this approach to risk, consider the Apollo space program. Surely no one would say that there is no risk in going to the moon, yet the program has had no accidents, and its risk index would be zero by the accident rate approach. However, since only four flights have been made the program obviously has limited exposure. If 10,000 flights were made with the same record of no accidents, then it would seem valid to say that going to the moon had a risk close to zero. In a test and development phase like the initial Apollo flights, a Bayesian approach would probably be the best approach to risk analysis. However, operational Naval aviation is well beyond these early developmental stages and sufficient exposure exists for all aircraft evaluated herein to assume that the use of the accident rate as a risk index is a valid approach.

C. DATA COLLECTION AND ANALYSIS

To better evaluate overall risk, the risk rates first had to be calculated. Since a Poisson model was being used, calculating the risk rates was the same procedure as estimating the parameter of the Poisson process of accidents in each risk area. To construct a risk rate for each risk area two separate pieces of data were needed. The first of these was

the number of accidents in a given risk area. This was obtained by a computer sort of accident records. The exact procedures of the sort and a flow chart of the sort program are given in Appendix F. In the same appendix a discussion on the data available at Naval Safety Center is also given. The other piece of data needed to construct a risk rate was the time spent in each risk area for each aircraft. This type of data was difficult to obtain because a time breakdown of total aircraft time by risk areas does not exist. The master aircraft time file does not account for time in these specific areas. Because of this, some method had to be devised to obtain time in the risk areas to make the risk analysis technique tractable. The cost and scale of a debrief type analysis to obtain time in the risk areas was considered prohibitive. Also, if a debriefing type program were used to obtain data, estimates would probably still be given since aircrews really do not specifically keep track of time in these four areas. Because of these restrictions, a Delphi type approach was used to obtain the time estimates by risk areas. The sources used were the aircraft analysts at the Naval Safety Center, men who evaluate the safety and are experts on a specific aircraft, and three squadrons which operated each aircraft. First, an average sortie time was obtained for the aircraft of interest by dividing the total amount of flight time over the period of interest by the total number of flights. Based on this average sortie time, the experts were asked to estimate how many minutes

or fractions of minutes of this average flight would be spent in each of the four risk areas. Climb and descent information were obtained separately and combined into the transistion phase data in the analysis. In this manner time estimates for the four risk areas were obtained for each aircraft studied. The variance in the estimates for each aircraft was due in part to the differences in local area procedures and specific missions of each squadron. It is not solely variance due to errors in estimation. This variance was needed in the analysis to give a true total picture of an average flight profile for each aircraft. A more detailed analysis might look at a given type aircraft in a given location and find its time in the risk areas exactly. However, in this initial look at risk, only the average time of an aircraft in each of the risk areas was used.

After the initial collection of data on time estimates, the average time in each risk area was shown to the analyst concerned for any comment or revision he felt relevent. Any disagreement with an estimate resulted in the collection of more data on that specific aircraft in the area in question. This process was followed by a re-evaluation by the analyst. By this iterative Delphi method a reasonable estimate of exposure to risk, given in the analysis by percent of flight time in each risk area, was developed. The results of this Delphi analysis are given in Table V. By taking the total flight time over a given period and using the exposure data obtained, time spent in each risk area could be determined.

Combining this time with the number of accidents in that risk area over the same period yielded a risk rate for each area and each type aircraft. These results are given later in the discussion section in Table I.

One problem generated by this method of obtaining data by the Delphi method, which was considered to be the only method that could reasonably be used, was a reduction in some possible areas of interest. For example, it was hoped an investigation into takeoff and landing rates in both ship and shore environments could be made. Because the time estimates for takeoff and landing were so variable, it was felt that extending these estimates by estimating how much time was spent in the ship phase of operations was too great an extension of the Delphi technique to give valid results. Also, it had been hoped to break up the inflight portion of risk into cruise and mission risk areas. The accident codes would permit sorting the accidents in this way, but again time estimates in these areas were too variable to be used with any degree of confidence. The data was sorted by ship/shore and cruise/mission criteria simply to give some idea of the contributions of these areas to the basic risk rates. The inflight risk rate is, in effect, somewhat like the present accident rate in that it is not really one constant rate but is made up of areas with risk rates of their own. A sensitivity analysis was done to determine how significant the cruise and mission risk rates might be if they were used. The results were that, compared to the takeoff and landing

risk rates, the breakdown of the inflight phase into cruise and mission areas does not yield significant additional information (Appendix B). Thus, the inflight rate is to be interpreted to reflect the overall risks and performance in both the cruise and mission phases of flight for each aircraft. A future study might look into the ship/shore and cruise/mission risks in more detail by getting good time estimates for the specific areas, and then using the risk analysis procedure developed here. Using this technique, risk rates for areas such as ship takeoff, air combat maneuvering, glide bombing, etc. could be found.

Since the overall accident rate is made up of the sum of the individual risk rates multiplied by the exposure to each risk, two pieces of data (number of accidents and total flight time) were needed to construct a risk index for each aircraft. Since these two pieces of data are already included in the present accident rate, the calculation of a risk index was reduced to calculating the accident rate of each aircraft. This calculation was done for the major Naval operational and training aircraft. Specifically, these were; A-3, A-4, A-5, A-6, A-7, F-4, F-8, E-2, P-3, S-2, T-28, and T-2. The period of primary interest, fiscal year 1969 through fiscal year 1973, was selected as a representative five year period in which the risk rates had sufficient time to stabilize, yet not too long that any of the basic risks or exposures changed.

D. DISCUSSION OF RESULTS

The computed table of risk rates, Table I, can be analyzed to obtain a great deal of relevent and useful information. For instance, it can be seen that the attack and fighter aircraft have the highest inflight accident rates. This is expected, since, as was mentioned previously, this rate reflects what an aircraft does inflight. Obviously the inflight risk rates reflect the well known fact that these type aircraft face the most risk inflight. By using the risk rate approach, this fact is shown in a more quantitative manner. By looking at Table II, the risk rates and accident breakdown by ship/shore criteria, it can be seen that the high takeoff rates are due about equally to ship and shore operations for most aircraft. The exceptions to this are the F-4 and the A-7, which both have a great number of ship takeoff accidents. It can be seen that aircraft with a large number or great proportion of their takeoff accidents on the ship tend to have the higher takeoff risk rates. This indicates a definite trend toward the ship being a great risk for takeoff.

In the landing risk area, the high landing risk rates are due mainly to shipboard operations. It can be seen that only three aircraft, the A-3, A-5, and F-8, have extremely high landing risk rates. A closer look at the accident breakdown shows that all of these rates consist mainly of carrier type landing accidents. This point is further demonstrated in Table III which shows the ship landing risk rates

for the fighter and attack type aircraft. The exposure estimates for this table are only approximations, and are not as valid as those of the risk area analysis. The calculation was done only to get some idea of what the ship landing rate might be like. The F-8's very high ship landing risk rate is due in part to the fact that it primarily operates off of the smaller carriers, and thus its higher landing risk rate reflects the higher risk of operating off of a small deck carrier. Some further analysis was done on the breakdown of day/night risk rates for the high performance (i.e., fighter and attack) aircraft in the landing risk area. The results are given in Table IV. As can be seen, the night landing risk rates are generally quite a bit higher than the overall landing rates. These sub-analyses were done to investigate the factors contributing to the overall trend of high landing risk rates. Obviously night and carrier operations are major factors in the landing risk. It would be interesting and profitable to extend the day/night breakdown analysis to other risk areas, but unfortunately exposure data is only specifically kept by the day/night criteria in the landing phase of operations.

The transistion risk rates are, except in two cases, higher than the inflight rates. High transistion risk rates in the single engine, single piloted aircraft, i.e., the A-7, A-4, and F-8, were expected since these aircraft have no backup for the pilot or engine in the critical phases of climbout and descent. This expectation held true with one

			Risk Area	
Aircraft	Takeoff	Inflight	Transistion	Landing
A-3	23.86	.46	.54	24.40
A-4	38.98	.78	1.58	10.13
A-5	31.14	1.64	1.36	48.26
A-6	20.81	.93	1.93	2.96
A-7	30.99	1.22	1.82	10.99
F-4	40.56	1.27	1.48	13.52
F-8	24.64	2.08	2.63	68.20
E-2	29.50	.12	.96	13.41
P-3	1.63	.04	.08	1.09
S-2	7.15	.54	.51	5.30
T-28	6.36	.19	.23	1.00
T-2	6.60	.50	.63	.71

The above rates are given in number of accidents per 10,000 risk type hours, e.g., for every 10,000 hours of time spent during takeoff, the A-3 had 23.86 takeoff accidents.

For reference purposes in evaluating the above tables, the Risk Indices of the aircraft for FY 69 through FY 73 are given below:

Aircraft	Risk Index	Aircraft	Risk Index
A-3	1.41	F-8	4.22
A-4	1.68	E-2	1.03
A-5	3.39	P-3	.07
A-6	1.38	S-2	.70
A-7	2.16	T-28	.34
F-4	2.21	T-2	.66

Table I. Risk Rates, FY 69 Through FY 73.

	Takeoff			Risk Area		Landing		
	Accidents					Accidents		
Aircraft	Ship	Shore	Rate	Inflight	Transition	Ship	Shore	Rate
A-3	4	1	23.86	.46	.54	13	7	24.40
A-4	25	37	38.98	.78	1.58	36	47	10.13
A-5	4	0	31.14	1.64	1.36	12	2	48.26
A-6	9	5	20.81	.93	1.93	2	4	2.96
A-7	29	9	30.99	1.22	1.82	27	17	10.99
F-4	23	17	40.56	1.27	1.48	32	30	13.52
F-8	4	11	24.64	2.08	2.63	66	10	68.20
E-2	3	0	29.50	.12	.96	4	1	13.41
P-3	N/A		1.63	.04	.08	N/A		1.09
S-2	2	4	7.15	.54	.51	2	14	5.30
T-28	2	5	6.36	.19	.23	1	10	1.00
T-2	2	6	6.60	.50	.63	0	6	.71

Table II. Risk Rates, Ship/Shore Breakdown, FY 69 Through FY 73.

Aircraft	Total Landings	Total Embarked Landings	% Embarked
A-3	201,353	28,851	14.3
A-4	1,384,780	155,186	11.2
A-5	99,182	17,464	17.6
A-6	379,032	65,833	17.4
A-7	822,294	173,898	21.1
F-4	994,773	144,617	14.5
F-8	414,824	59,471	14.3

Aircraft	Ship Landing Time	Ship Landing Accidents	Embarked Landing Risk Rate
A-3	1172.3	10	85.30
A-4	9180.8	10	10.89
A-5	510.4	4	78.37
A-6	3529.9	2	5.66
A-7	8450.4	16	18.93
F-4	6324.9	18	28.46
F-8	1593.5	39	244.73

Table III. Landing Risk Rates, Ship/Shore Breakdown, FY 69 Through FY 73.

Aircraft	Total Landings	Landing Data Total Night Landings	% Land at Night	Total Night Landing Time	Night Landing Accidents (Ship)		Rate
A-3	201,353	81,774	40.6	3328.4	13	(10)	39.06
A-4	1,384,780	308,074	22.2	18197.9	16	(10)	8.79
A-5	99,182	43,736	44.1	1279.3	4	(4)	31.26
A-6	379,032	141,317	37.3	7567.1	3	(2)	3.96
A-7	822,294	334,186	40.6	16260.0	22	(16)	13.54
F-4	994,773	281,292	28.2	12300.9	25	(18)	20.32
F-8	414,824	120,236	29.0	3231.7	41	(39)	126.86

Aircraft	Landing Risk Rate	Night Landing Risk Rate
A-3	24.40	39.06
A-4	10.13	8.79
A-5	48.26	31.26
A-6	2.96	3.96
A-7	10.99	13.54
F-4	13.52	20.32
F-8	68.20	126.86

Table IV. Landing Risk Rates, Day/Night Breakdown, FY 69 Through FY 73.

Aircraft (Avg. Sortie Length)		Risk Area		
	Takeoff	Inflight	Transition	Landing
A-3 (2.3)	.80	74.87	21.20	3.13
A-4 (1.6)	.91	79.56	14.84	4.69
A-5 (1.8)	1.74	74.42	19.90	3.93
A-6 (1.9)	1.31	83.65	11.09	3.95
A-7 (1.7)	1.35	75.53	18.70	4.41
F-4 (1.5)	.97	79.46	15.28	4.29
F-8 (1.6)	1.42	77.36	18.61	2.60
E-2 (2.6)	.96	75.96	19.55	3.52
P-3 (5.1)	.52	87.96	9.97	1.55
S-2 (2.8)	.67	89.03	7.74	2.56
T-28 (1.3)	1.03	72.36	16.35	10.26
T-2 (1.3)	1.92	69.56	15.06	13.46

Table V. Exposure to Risk - (By Percent of Flight Time).

exception. The three aircraft just mentioned ranked first, third, and fourth in transition risk rate, with the A-6 ranking second. This anomaly was investigated further and it was found to be valid, the A-6 having a high number (8) of climbout accidents in the period investigated. This in turn reflected an engine problem the A-6's had during this period which, as noted by the risk rate, increased their risk in the transition phase. Much more analysis could be done on the risk rates in all risk areas to answer many specific questions concerning risk.

By using the Poisson model and the accident rate approach to risk analysis the reason why accident rates differ from aircraft to aircraft is readily apparent. By looking at the exposure to risk and the performance in the risk areas, two independent pieces of information used in the Poisson model, it can be seen why the present accident rates are like they are. For example, the P-3 is exposed to the takeoff and landing risks less than any aircraft, and it performs in the takeoff risk better than any aircraft, and is second best in landing risk rate. It is exposed to the inflight risk more than any aircraft, yet its inflight rate, i.e., its performance in the inflight area, is so low, since it faces so few risks inflight, that this is not a major factor in its overall safety record. Its transition risk rate is also the lowest of all the aircraft studied. All of these factors combine to say that the P-3 should be one of the safest aircraft in the Navy. This is,

of course, true. As another example of what risk analysis can tell us, we see that the T-2 is exposed to the landing risk more than any aircraft (13.46% of a flight). This is because it is a jet trainer aircraft, and it has relatively short flights with a significant proportion of landing practice in each. Despite its great exposure to the landing risk, the T-2 performs so well in this critical risk area that its overall accident rate, or risk index, is low when compared to other jet aircraft.

The general "U" shape of the risk rates for all aircraft is consistent throughout the analysis with the takeoff and landing rates high compared to the inflight and transition rates. The actual magnitude of each risk rate is determined strictly by the aircraft's performance in that risk area. This approach to risk analysis explains in more quantitative terms what is shown by the present accident rate. In other words, the present accident rate shows that a P-3 is safer than an F-8 since it has a lower risk index. However, the risk index by itself does not really indicate why it is safer. By looking at the development of the risk index, though, we are able to answer this question by looking at the exposure to risk and the performance in the risk areas. The risk analysis points out that these two factors, exposure and performance, are the two keys to understanding the reasons for differences in accident rates. Contained in the performance figures are also other risk factors such as single pilot risk, carrier operation risk, and a multitude of different

risks which various aircraft face in a flight. By just a cursory look at the exposure and performance figures used in the analysis a good idea of what an aircraft's accident rate will be relative to other aircraft is obtained. This is the object of risk analysis, and it is what the development of a risk index and the risk rates makes possible.

E. PREDICTION OF RISK INDEX

After the initial formulation of the ideas on risk analysis, it was hypothesized that perhaps the theory and techniques being used to evaluate the risk of an operational aircraft might somehow be extended to include prediction of risk for aircraft which were not yet operational. This would enable the Navy to predict to some degree the safety performance of its new aircraft.

It was obvious that the present data on accident and risk rates was an ideal base from which to formulate any prediction. It was assumed that a Bayesian type *a priori* set of risk rates would be a valid and tractable technique to use in the approach to prediction of risk and risk rates. This *a priori* risk rate would be based on three factors: 1) risk rates of aircraft with similar flight characteristics, 2) proposed exposure to risk areas, and 3) experience with similar type aircraft. From these components a projected risk index could be determined for a new aircraft. This *a priori* risk index would give the Navy some indication of what to expect in the way of safety performance from the aircraft.

The Bayesian approach here does not contradict what has previously been decided in the rejection of the Bayesian type approach for the assignment of a risk index to an aircraft.. As mentioned previously, the aircraft being evaluated were operational aircraft, and data in the form of actual performance in the risk areas was available for use in determining risk. The exposure was also great enough to assume that the accident rate was somewhat "steady state". In the case of prediction this type of complete data would not be available due to the limited exposure of the aircraft.

Another approach to this problem of prediction could be through the application of renewal and reliability theories. It could be assumed that the accident rate of a new aircraft was in fact a failure rate which is (hopefully) decreasing. The steady state rate would be the actual risk index for the aircraft. This type of model would require a failure rate which is gamma distributed, with the shape parameter less than one. Unfortunately, the lack of any real data in the critical areas of the failure curve precludes using this model and this approach. Of note in this approach is the fact that the accident rate would be, in reliability terminology, a hazard rate or failure rate. Strictly speaking, this is in fact what the accident rate is. However, to be consistent with aviation safety terminology it will continue to be referred to as a risk rate.

As an example of the Bayesian approach to risk index prediction, a projected accident rate for the F-14 will be

computed. First, it can be assumed that the most similar aircraft to the F-14 in the exposure to risk would be the F-4. However, the F-4's exposure times must be modified somewhat to reflect the F-14's greater endurance. The actual takeoff, landing, and transition times will be similar, but all of these will be a smaller proportion of the total flight due to the longer total flight time. In other words, the F-14 will be exposed to these three risks less than an F-4. Since takeoff, transition, and landing risk areas are reduced in exposure, the inflight area is naturally increased in exposure. Just by the exposure considerations alone it can be seen that if an F-14 performed exactly the same as an F-4 it would have a slightly lower accident rate due to the lessened exposure in the critical risk areas of takeoff and landing. However, the F-14 will most likely not perform like an F-4. The major reason for this change in performance is the F-14's variable geometry wings. These give the F-14 a great performance advantage over the F-4 in virtually all risk areas. In the takeoff area the wings allow a lower lift off speed and a lower stall speed. A comparable aircraft, performance wise, would probably be an A-6. In the transition phases of climbing and descending the variable sweep wing again lowers the stall speed and makes the aircraft much more stable in critical transition phases. In the landing phase the wing should again give the F-14 the performance characteristics of an A-6, i.e., it should perform very well in this phase. In the

inflight phase the risk rate will probably be lower than the F-4's even though the F-14 is exposed to this risk more. The reason for this is seen in the fact that a great proportion of the fighter aircraft inflight accidents are stall/spin accidents which occur during air combat maneuvering. Because of the F-14's computer controlled variable sweep wings, the aircraft has not yet been spun. This characteristic should make the F-14's inflight risk rate low compared to the F-4's.

In Table VI the F-14 prediction data and a predicted risk index are presented.

Predicted Exposure[1]

(F-4 values given in parentheses)

Takeoff	Inflight	Transition	Landing
.79% (.97)	83.08% (79.46)	12.50% (15.28)	3.63% (4.29)

Predicted Risk Rates

a priori risk rate		reason
Takeoff	20.0	similar to A-6 takeoff risk rate
Inflight	1.0	slightly lower than F-4 risk rate
Transition	1.3	slightly lower than F-4 risk rate
Landing	5.0	similar to and slightly more than A-6 landing risk rate.

Risk Index Calculation

$$\text{Accident rate} = \sum_i (\text{risk rate})_i \cdot (\text{exposure})_i$$

$$= (20)\cdot(.0079) + (1)\cdot(.8308) + (1.3)\cdot(.125) + (5)\cdot(.0363)$$

$$= .158 + .8308 + .1625 + 1815 = 1.33$$

Projected F-14 accident rate is 1.33 accidents/10,000 hours.

Table VI. Prediction of Risk Index for F-14.

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[1] Estimates from Captain Clyde Tuomela, Head, Aviation Safety Programs and former NAVAIRSYSCOM Deputy Program Manager, F-14 Test and Evaluation.

II. COMPARATIVE ANALYSIS

A. BACKGROUND

Now that the different risk rates and their contributions to the overall risk measure have been investigated, it would be worthwhile to have some method to compare aircraft with respect to safety performance and determine which is actually performing the best when differences in risk are taken into account. This type of comparison would enable us to look at different aircraft and compare them in a "normalized" risk environment. From this comparison a determination could be made about how an aircraft is performing safetywise while accounting for the risks it faces. Since it has already been shown how risk varies from aircraft to aircraft, it is evident that comparing the present accident rates directly to compare safety performance yields deceptive results. Comparing accident rates is really comparing both safety performance and differences in risk. If all aircraft operated in the same risk environment and had the same performance characteristics, then comparing accident rates would be a valid procedure of comparing safety performances. However, since no two risk environments are the same, comparing accident rates does not account for the differences in risk of each aircraft. Because of this, two statistics are proposed which can help compare aircraft safetywise in a more productive and valid manner.

B. COMPARATIVE MEASURES

1. Improvement Index

To account for the risk differential in aircraft, a comparative statistic was developed which was based on the theory of using each aircraft as its own control with respect to risk. This procedure is logical since each aircraft is unique in its exposure to risk, its performance in the risk areas, and the specific types of risk it faces in each risk area. To compare aircraft to each other, the first step was a normalizing step which compared each aircraft to itself with respect to safety performance. One way to do this normalization was by comparing an aircraft's difference in safety performance (accident rate differential) to an average rate over some specified period. By doing this we can see the difference in how well the aircraft performed when exposed to essentially the same risks. It is necessary to compare the differences in accident rates to an average rate because the difference in risk alone is not a normalized measure. For example, the difference in P-3 accident rates would be, at most, .16 while the difference in F-8 accident rates could be as much as 2 or 3. Thus a difference of accident rates divided by the average rate over a somewhat uniform risk period is a good measure to use to normalize all aircraft safetywise. A statistic to do this is designated an Improvement Index (II) and it is calculated as follows:

$$II_i = \frac{(\text{accident rate in year } i\text{-}1) - (\text{accident rate in year } i)}{\text{average accident rate in years } i\text{-}1 \text{ and } i} .$$

If consecutive years have accident rates of zero the II is arbitrarily set to +1, a figure rewarding consecutive zero accident rates with an indication of substantial improvement. This statistic assumes that over the two year period of interest, years i-1 and i, the aircraft faces basically the same risks. It then evaluates how well it faced these risks in year i versus year i-1. This statistic has an analytical interpretation based on the Poisson model used in risk evaluation. To see this, we first must assume that the aircraft flies about the same amount of hours in years i and i-1. This implies that the average accident rate over these two years is equal to the average of the two years accident rates. Next, we observe that the accident rates in years i and i-1 are the rates of two independent Poisson processes. Finally, we note that the period covered by the years i and i-1 can be considered a period (0,t) in which both processes occur. If these assumptions are true, the II is then equivalent to:

2((probability one accident in year i-1 given one accident in years i and i-1) - (probability one accident in year i given one accident in years i and i-1)).

The actual analytical derivation of the above formula is presented in Appendix D.

The improvement index has several desirable attributes. First, it is positive if the aircraft improved in safety performance and negative if it declined. This is an obvious necessity for an improvement measure. Second, the

range of the II is from +2 to -2 for all aircraft, thus normalizing all to a common scale. The index is also not biased in either the positive or negative direction. Finally, the index only compares an aircraft to itself. This means that the value of the II is dependent only on the aircraft's risk performance as compared to the risks it faces, and it is not influenced by the actual magnitude of the accident rate.

By using the improvement index a direct comparison of all aircraft can be made in any given year. This is possible because the trends in safety performance of the aircraft have been reduced to probabilities and do not depend directly on the number of accidents or the hours flown. The aircraft with the most positive II has improved the most in a year as compared to the previous year. On the other hand, the one with the most negative II declined the most, or in other words, performed worst in its risk areas considering the risks it faced. Table VII shows values of the improvement index for the aircraft studied over the period fiscal 1969 through fiscal 1973.

2. Weighted Improvement Index

Of further interest in comparing aircraft safetywise is the question of which aircraft is the prime contributor to the overall safety record and which is the major detractor. The improvement index does not really give this information since it only indicates how much an aircraft improved or declined in performance and not how significant that aircraft

	Fiscal Year				
Aircraft	73	72	71	70	69
A-3	- .75	+1.01	- .48	+ .43	+ .27
A-4	- .20	+ .16	+ .48	- .09	+ .01
A-5	+1.29*	- .15	+ .95*	+ .34	- .29
A-6	- .14	+ .25	+ .10	- .31@	+ .18
A-7	+ .58	+ .02	+ .40	+ .11	- .02
F-4	- .32	+ .42	- .03	- .04	+ .10
F-8	- .41	+ .70	+ .19	+ .26	- .64@
E-2	- .94@	+1.11*	-1.10	+ .84	- .22
P-3	+1.00	-1.50@	-2.00@	+1.86*	+ .38
S-2	+ .59	+ .36	- .47	- .17	0
T-28	- .39	+ .43	- .16	- .24	+ .63*
T-2	+ .83	+ .28	- .13	+ .42	+ .31

$$II_i = \frac{(\text{accident rate in year } i-1) - (\text{accident rate in year } i)}{\text{average accident rate in years } i \text{ and } i-1}$$

If denominator equals 0, $II_i = + 1.00$.

* best in year

@ worst in year

The above figures use each aircraft as its own control and show relative improvements in any given year. They can be used to directly compare aircraft in a given year with respect to safety performance.

Table VII. Improvement Index (II).

is to the overall safety record. One way to look at each aircraft's contribution would be to look at the magnitude of the rates for each aircraft in a year and compare these rates to the overall rate for the year. However, this approach does not account for differences in risk between the aircraft compared. Since the II does account for this factor, and also gives the amount of improvement for each aircraft individually and normalizes them, it should be a good basis for the new measure. To account for the safety contribution of an aircraft a weight was applied to each improvement index. This weight could have been based on one of two factors available in safety analysis, hours flown by an aircraft or number of accidents. Since once a valid exposure is established hours flown are not significant (i.e., the accident rate is somewhat steady state), the weight chosen was based on the number of accidents. Specifically, the weight was the percent of the total number of accidents that a particular aircraft had over the two year period covered by the II. A percent of the total number of accidents was used instead of just the number of accidents so that all weights would be in a fixed range (0,100) and all would add to 100 for any year. This weighting factor placed more emphasis on the aircraft with the most accidents, and in this sense contributed the most to the overall safety record. The resulting statistic is called a Weighted Improvement Index (WII), and it is calculated as follows for each type aircraft:

$$WII_i = II_i \times \frac{(\text{total \# of accidents by aircraft in years } i-1,i)}{(\text{total number of accidents in years } i-1,i)} \times 100.$$

For aircraft with many accidents even a small improvement index will yield a large WII, indicating a major contributor or detractor to overall safety in the year. On the other hand, aircraft with a small number of accidents, in most cases the low risk aircraft, would need a great change in their accident rate, yielding a large improvement index, before they were of concern. Table VIII shows the WII for the period fiscal 1969 through fiscal 1973.

C. DISCUSSION OF RESULTS

By using the improvement index and the weighted improvement index all aircraft can be compared directly and on equal terms because risk differences have been accounted for. In looking at the improvement index table it is evident that in general the higher risk aircraft don't have large II's. The only exception to this is the A-5, which has a large II in both 1973 and 1971. In both these years the A-5 performed so well with respect to the risks that it faced that it had one of the highest improvement indexes. Another piece of information that can be seen in the table is that the magnitude of the positive II's (those showing improvement) are generally much greater than the magnitudes of the negative II's. This is obviously a good property showing an overall trend to improved safety performance. One problem inherent to the II is that it can get into cycles when an aircraft has a very good or very bad year. In this case, the next

	Fiscal Year				
Aircraft	73	72	71	70	69
A-3	- 2.05	+ 3.41	- 1.67@	+ 1.25	+ 1.13
A-4	- 4.55	+ 3.30	+11.74*	- 2.59@	+ .12
A-5	+ 2.37	- .34	+ 2.23	+ 1.05	- .87
A-6	- 1.14	+ 1.84	+ .61	- 1.43	+ .59
A-7	+11.78*	+ .42	+ 6.89	+ 1.65	- .19
F-4	- 7.32@	+ 8.78*	- .48	- .71	+ 1.69
F-8	- 3.71	+ 8.05	+ 3.07	+ 5.12*	-11.87@
E-2	- 1.14	+ 1.15	- .86	+ .55	- .17
P-3	+ 1.22	- 1.56@	- .38	+ .91	+ .42
S-2	+ 1.62	+ 1.41	- 1.46	- .43	0
T-28	- 1.30	+ 1.58	- .59	- .67	+ 2.19*
T-2	+ 2.02	+ 1.04	- .44	+ 1.69	+ 1.68

$\mathrm{WII}_i=\mathrm{II}_i\,\mathrm{x}$(% of total accidents in years i and i-1 that aircraft had)

* best in year

@ worst in year

The magnitudes of the figures indicate significance of aircraft's safety performance to overall Naval aviation safety, with differences in exposure and risk. In effect, it shows where the primary praise (most positive) and blame (most negative) can be assigned for any given years safety record. Looking along rows shows specific aircraft's safety trend.

Table VIII. Weighted Improvement Index (WII).

year's II will usually change sign and be rather large. An example of this process is the E-2 in the 1970 to 1973 time frame.

It is in the WII table that the most useful information is found. It can be seen that the positive numbers are again larger than the negative, although not by as much as in the II case. It is also evident that the cyclic type pattern exhibited by the E-2 in the II table is absent here. Instead we get some indication of which aircraft really did improve the most be considering both its performance (II) and its significance (% of total accidents). An example of this is found in the 1973 statistics. In that year the A-5 did so well (the II was + 1.29) that, even though it had a small proportion of the total accidents (1.8%) it was the second most significant contributor to the years safety record. On the other hand, in 1972 the P-3, which has a very low risk (.16), did so poorly that it was the major negative contributor to the overall safety record. This is despite the fact that it had only 1% of the total number of accidents. Many other examples and answers to particular questions can be found in these two tables.

By using this type of comparative analysis on the risk indices of aircraft, a true and useful representation of the actual safety performance can be found. A similar procedure for calculating the II and WII could also be followed in each of the risk areas to give information on particular risk area safety trends if desired.

III. CONCLUDING REMARKS

"It has long been recognized that to prevent accidents, it is necessary to study accidents to identify causes and detect problem areas so that corrective action can be initiated".[2]

The analysis carried out in this thesis is a first attempt at a more enlightning evaluation of risk to gain a better understanding of differing accident rates in the context of overall aviation safety. The risk rates developed are a unique and extremely helpful concept to evaluate an aircraft's overall safety performance by evaluating how it performed in certain risk areas. The risk rates are also very helpful, in conjunction with the exposure data, to investigate and evaluate the total risk of an aircraft. Risk itself is an elusive quantity that is hard to define, and harder yet to calculate. It is felt that the measure of risk proposed here is a valid measure of total risk, i.e., actual and inherent risk. Much more defined and specific risk measures of these two factors would require more data than is now available, particularly in the area of exposure to risk. Nevertheless, even in their general context the risk index and the risk rates can be used profitably by Naval Safety Center and operational commands to gain insight

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[2] Gilpin, L. H., "Ask Not What You Can Do For the Computer, Ask What the Computer Can Do For You", Approach, p. 19, March 1974.

into where the primary risks for an aircraft lie, and how the aircraft are performing in these risk areas.

The comparative measures that are proposed by using the results of the risk analysis are new and worthwhile measures that can be used as an excellent evaluation tool. Measures of this form to detect trends and magnitudes of contributions to safety performance are not now available. With so much emphasis today on safety trends and improvement in safety performance, these measures will add significantly to the analysis and evaluation of all Naval aircraft. The measures are readily available from existing data and will be a definite contribution to the safety analysis done at Safety Center as well as at all major aviation commands.

As implied by the initial quote, it is hoped that this study can achieve the primary goal of all safety studies -- to contribute to the prevention of accidents. It is felt that the analysis presented herein can achieve this goal, and thus prove its worth in more than a strict academic sense, but in a safety context also.

APPENDIX A: POISSON DATA

Poisson Theory

Theorem: Suppose that we know that n events, $n \geq 1$, of a Poisson process have occurred by time t. Then the set of n arrival times, $\{U_1 \ldots U_n\}$, has the same distribution as a set of n random variables which are independent and uniformly distributed on the interval (0,t).[3]

One way to test if a given process is a Poisson process is to observe it for a period of time, T. We record each event in that time period, and the time it occurred (U_i), measured from the start of the period. According to the above theorem, if the events are following a Poisson process the times at which the events occur should be independent and uniformly distributed over the period T. Thus we need only test to see if our observed times are independent and uniformly distributed. One way to do this is to use the fact that, according to the Central Limit Theorem, for moderately large values of n, the sum

$$S_n = \sum_{i=1}^{n} U_i$$

of n independent random variables, each uniformly distributed on the interval 0 to T, may be considered to be normally

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[3] Ross, Introduction to Probability Models, p. 126, Academic Press, 1972.

distributed with mean

$$E(S_n) = nE(U_1) = n\frac{T}{2}$$

and variance

$$Var(S_n) = nVar(U_1) = n\frac{T^2}{12} .$$

The test is then to see if S_n satisfies the inequalities

$$E(S_n) - 1.96(var(S_n)) \leq S_n \leq E(S_n) + 1.96(var(S_n)).$$

If it does, we would accept the hypothesis that the observed events are of the Poisson type. The test has a 95% level of significance.[4]

Poisson Test of All Accidents, FY 70

$$S_n = \sum_{i=1}^{n} U_i = 78915$$

$$T = 365$$

$$n = 439$$

$$E(S_n) = nE(U_1) = n\frac{365}{2} = n(182.5) = 80117.50$$

$$Var(S_n) = nVar(U_1) = n\frac{(365)^2}{12} = n(11102.08) = 4873814.57$$

$$S.D. = \sqrt{Var(S_n)} = 2207.67$$

$$\mu - (1.96)(S.D.) = 80117.50 - 1.96(2207.67)$$

$$= 80117.50 - 4327.03 = 75,790.47$$

$$\mu + (1.96)(S.D.) = 80117.50 + 4327.03 = 84,444.53.$$

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[4] Parzen, Stochastic Processes, p. 141, 142, Holden-Day, 1962.

To be Poisson, with 95% level of significance:

$$\mu - (1.96)(SD) \leq S_{439} \leq \mu + (1.96)(SD).$$

For FY 70 we get:

$$75{,}790.47 \leq 78{,}915 \leq 84{,}444.53.$$

Therefore the accidents for FY 70 can be considered a Poisson process.

Poisson Test for A-7 and Prop Aircraft, FY 72

A-7 Aircraft

$$S_n = \sum_{i=1}^{n} U_i = \sum_{i=1}^{43} U_i = 7211$$

$$T = 365$$

$$E(S_n) = n(182.5) = 43(182.5) = 7847.5$$

$$Var(S_n) = n(11102.1) = 43(11102.1) = 477389.6$$

$$S.D. = 690.9$$

$$\mu - 1.96(SD) = 7847.5 - 1354.2 = 6493.3$$

$$\mu + 1.96(SD) = 7847.5 + 1354.2 = 9201.7$$

$$6{,}493.3 \leq 7{,}211 \leq 9{,}201.7 \quad \text{So Poisson Q.E.D.}$$

Prop Aircraft (C1,C2,E1,E2,P3,C130,S2)

$$S_n = \sum_{i=1}^{19} U_i = 3815$$

$$T = 365$$

$$E(S_n) = 19(182.5) = 3467.5$$

$$Var(S_n) = 19(11102.1) = 210939.5$$

$$S.D. = 459.3$$

$\mu + 1.96(SD) = 3467.5 + 900.2 = 4367.7$

$\mu - 1.96(SD) = 3467.5 - 900.2 = 2567.3$

$2{,}567.3 \leq 3{,}815 \leq 4{,}367.7$ So Poisson Q.E.D.

Poisson Test, A-7 Landing and Inflight Accidents

A-7 Landing Accidents

$$S_n = \sum_{i=1}^{30} U_i = 14606$$

$T = 1095$ (FY 70, FY 71, FY 72)

$$E(S_n) = n\frac{T}{2} = 30(547.5) = 16425$$

$$Var(S_n) = n\frac{T^2}{12} = 2997562.5$$

$S.D. = 1731.3$

$\mu - 1.96(SD) = 16425 - 3393.4 = 13031.6$

$\mu + 1.96(SD) = 16425 + 3393.4 = 19818.4$

$13{,}031.6 \leq 14{,}606 \leq 19{,}818.4$ So Poisson Q.E.D.

A-7 Inflight Accidents

$$S_n = \sum_{i=1}^{33} U_i = 12560$$

$T = 730$ (FY 72, FY 71)

$$E(S_n) = 33(365) = 12045$$

$$Var(S_n) = 33\ \frac{730^2}{12} = 1465475$$

$S.D. = 1210.6$

$\mu - 1.96(SD) = 12045 - 2372.7 = 9672.3$

$\mu + 1.96(SD) = 12045 + 2372.7 = 14417.7$

$9{,}672.3 \leq 12{,}560 \leq 14{,}417.7$ So Poisson Q.E.D.

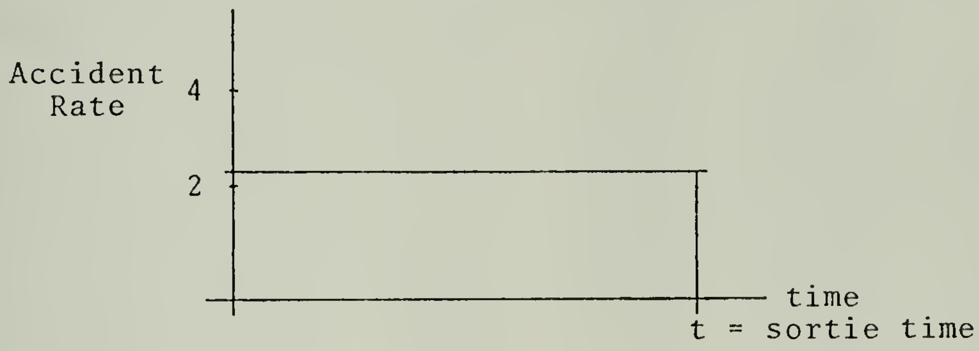
APPENDIX B: RISK DATA

Risk Area Breakdown

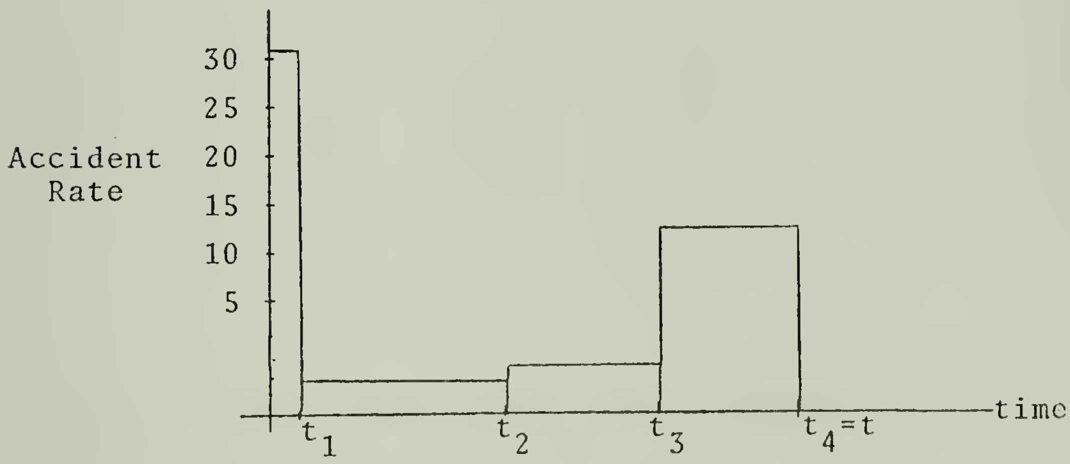
Theorem: Reproductive property of the Poisson process. If $X_1 \ldots\ldots X_n$ are independent Poisson random variables with parameters $\lambda_1 s_1 \ldots\ldots \lambda_n s_n$ respectively, then $Y = \sum_{i=1}^{n} X_i$ is also a Poisson random variable with parameter $\lambda = \sum_{i=1}^{n} \lambda_i s_i$.[5]

For an A-7 aircraft, a typical risk breakdown is:

Present Risk Profile



Revised Risk Profile



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[5] Larson, *Introduction to Probability and Statistical Inference*, p. 180, John Wiley & Sons, Inc., 1962.

0 to t_1 = takeoff time

t_1 to t_2 = inflight time

t_2 to t_3 = transition time

t_3 to t_4 = landing time

All accident rates are given in number of accidents per 10,000 hrs. Because of the reproductive property given above, the area under both curves is the same.

			Fiscal Year		
Aircraft	73	72	71	70	69
A-3	63.63	0	23.08	20.75	18.52
A-4	28.13	17.69	27.24	60.08	53.18
A-5	28.79	0	30.00	33.48	34.15
A-6	27.26	21.35	22.81	15.95	15.53
A-7	29.09	21.34	30.26	43.17	36.85
F-4	49.44	31.34	42.52	38.43	41.55
F-8	11.66	20.49	25.19	6.76	50.46
E-2	0	0	55.85	50.98	43.57
P-3	0	0	0	0	8.51
S-2	0	0	7.03	15.42	8.54
T-28	0	5.04	15.37	3.96	7.02
T-2	4.45	4.77	8.28	4.11	10.20

Table IX. Takeoff Risk Rates, FY 69 Through FY 73.

	Fiscal Year				
Aircraft	73	72	71	70	69
A-3	.68	0	.76	.44	.39
A-4	.64	.53	.70	1.05	.88
A-5	0	1.95	0	2.35	2.39
A-6	.73	.54	1.05	1.34	.95
A-7	.58	1.08	1.08	1.80	2.19
F-4	1.07	.96	1.36	1.52	1.41
F-8	1.71	.56	1.23	2.86	3.12
E-2	.59	0	0	0	0
P-3	0	.09	.05	0	.05
S-2	0	.16	.10	0	.03
T-28	.08	.21	.22	.34	.10
T-2	.24	.39	.57	.34	.84

Table X. Inflight Risk Rates, FY 69 Through FY 73.

	Fiscal Year				
Aircraft	73	72	71	70	69
A-3	0	1.11	0	0	1.39
A-4	1.29	1.30	1.46	2.71	1.18
A-5	0	2.43	0	0	2.98
A-6	.97	3.04	2.16	3.40	2.21
A-7	.70	2.57	1.64	1.73	3.10
F-4	1.74	.66	3.04	1.21	.88
F-8	2.67	1.56	3.20	2.58	2.89
E-2	2.30	2.47	0	0	0
P-3	0	.39	0	0	0
S-2	.68	0	1.21	.44	.37
T-28	.37	.32	.64	0	0
T-2	0	0	1.06	.52	1.30

Table XI. Transition Risk Rates, FY 69 Through FY 73.

	Fiscal Year				
Aircraft	73	72	71	70	69
A-3	16.26	15.07	36.50	26.52	23.66
A-4	9.55	5.49	7.93	11.66	140.71
A-5	0	12.31	39.86	59.29	90.72
A-6	6.78	2.36	5.04	0	0
A-7	3.96	8.71	10.42	20.55	16.92
F-4	16.15	11.81	12.02	13.04	14.61
F-8	38.22	27.98	73.40	77.63	96.46
E-2	12.78	0	30.46	0	23.76
P-3	2.63	0	0	0	2.85
S-2	4.11	5.58	7.36	4.03	4.47
T-28	2.38	0	.51	1.19	1.05
T-2	0	.68	0	1.76	.97

Table XII. Landing Risk Rates, FY 69 Through FY 73.

Aircraft	Inflight Risk Rate	Mission Risk Rate		Cruise Risk Rate
		Mission 50%	Mission 25%	Cruise 50%
A-4	.78	.59	1.18	.96
A-6	.93	.88	1.77	.98
A-7	1.22	1.10	2.22	1.34
F-4	1.27	1.23	2.48	1.31
F-8	2.08	1.99	3.98	2.17

The above figures indicate what the cruise and mission risk rates would be if cruise and mission were the indicated percentages of the inflight portion of a flight.

Table XIII. Cruise/Mission Sensitivity Analysis, FY 69 Through FY 73.

APPENDIX C: EXPOSURE DATA

		Mean (Variance) in minutes				
A/C	(Sortie) (time)	Takeoff	Climb	Inflight	Descent	Land
A-3	(2.3)	1.10 (.12)	14.60 (53.00)	102.90 (54.00)	14.60 (.22)	4.33 (.22)
A-4	(1.6)	.88 (.05)	7.50 (2.75)	76.40 (1.67)	6.75 (3.69)	4.50 (.75)
A-5	(1.8)	1.88 (.58)	11.00 (1.00)	81.80 (19.80)	10.50 (5.75)	4.25 (2.20)
A-6	(1.9)	1.50 (.25)	5.85 (3.10)	95.30 (2.75)	6.80 (1.60)	4.50 (1.25)
A-7	(1.7)	1.38 (.18)	8.58 (5.92)	79.50 (2.75)	10.50 (.75)	4.50 (1.25)
F-4	(1.5)	.875(.46)	5.25 (15.19)	71.50 (19.26)	8.50 (1.25)	3.86 (.55)
F-8	(1.6)	1.37 (.48)	8.62 (5.67)	74.31 (32.23)	9.25 (10.69)	2.50 (.25)
E-2	(2.6)	1.50 (.75)	18.25 (2.18)	118.50 (7.25)	12.25 (15.25)	5.50 (8.25)
P-3	(5.1)	1.60 (.68)	15.75 (1.68)	263.60(122.00)	14.75 (.19)	4.75 (5.98)
S-2	(2.8)	1.13 (.19)	5.25 (.69)	149.57 (7.40)	7.75 (4.19)	4.30 (3.87)
T-28	(1.3)	.80 (.10)	5.25 (.20)	57.90(141.00)	7.50 (8.25)	8.00 (41.00)
T-2	(1.3)	1.50 (.25)	6.00 (4.00)	48.75(103.10)	5.75 (.69)	10.50 (52.20)

Variance reflects different missions of aircraft and differences in squadron operations.

Table XIV. Time Estimates of Phases of Flight.

APPENDIX D: ANALYTICAL BASIS OF COMPARATIVE MEASURES

Letting r_i be the accident rate in year i for the aircraft of interest, the improvement index, by definition, is:

$$II_i = \frac{r_{i-1} - r_i}{r_{i-1,i}} .$$

If we assume that the average rate for the two years is:

$$r_{i-1,i} = \frac{r_{i-1} + r_i}{2} .$$

Then

$$II_i = \frac{(r_{i-1})}{\frac{r_{i-1} + r_i}{2}} - \frac{(r_i)}{\frac{r_{i-1} + r_i}{2}} = \frac{2(r_{i-1})}{r_{i-1} + r_i} - \frac{2(r_i)}{r_{i-1} + r_i}$$

$$= 2\left[\frac{r_{i-1}}{r_{i-1} + r_i} - \frac{r_i}{r_{i-1} + r_i}\right] .$$

The quantities in the brackets above can be interpreted in the following manner. Since the accident process in each year is of the Poisson type, the accident rates for years i, i-1, and both years combined are r_i, r_{i-1}, and $r_i + r_{i-1}$ respectively. From this fact it can be shown that if[6]

p = P[exactly one accident in years i-1 and i]

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[6] Ross, S. M., Introduction to Probability Models, Ch. 5, Academic Press, 1972.

$$= (r_{i-1} + r_i)\, e^{-(r_{i-1} + r_i)}$$

and

$$p_1 = \text{P[exactly one accident in year i-1 given one accident in years i-1 and i]}$$

$$= \frac{\text{P[one accident in year i-1 and none in year i]}}{p}$$

$$= \frac{r_{i-1}e^{-r_{i-1}}e^{-r_i}}{(r_{i-1} + r_i)e^{-(r_{i-1} + r_i)}} = \frac{r_{i-1}}{r_{i-1} + r_i} .$$

Using the same rationale, defining p_2 as the probability of exactly one accident in year i given one accident in years i-1 and i we get

$$p_2 = \frac{r_i}{r_{i-1} + r_i} .$$

The range of each of these ratios is from 0 to 1, and thus the improvement index will range from -2 to + 2.

APPENDIX E: MISCELLANEOUS DATA

FY	A-3	A-4	A-5	A-6	A-7	F-4	F-8
60	66,601	186,464					136,802
61	79,605	234,846					171,042
62	85,692	321,526					190,003
63	82,142	335,209	9,496			53,080	199,558
64	80,971	383,076	14,704			85,267	230,570
65	72,134	406,637	13,898	16,128		111,339	218,735
66	73,896	459,351	17,942	30,911		161,499	202,454
67	72,778	446,053	17,319	55,155	14,466	189,153	172,732
68	69,518	481,996	16,400	76,828	58,619	202,158	138,703
69	67,479	454,594	16,828	98,263	120,582	223,273	111,633
70	60,241	347,484	17,167	95,701	154,419	214,575	104,036
71	52,511	322,719	19,151	100,388	195,797	193,933	83,841
72	42,403	310,533	20,666	107,254	208,227	197,364	68,724
73	39,285	312,484	19,963	111,995	229,124	187,649	60,382

Table XV. Hours Flown, FY 60 Through FY 73.

FY	E-2	P-3	S-2	T-28	T-2
60				266,929	
61			265,391	266,952	
62			323,228	314,180	
63	149	20,987	255,618	276,927	88,332
64	2,356	57,010	312,269	285,357	82,306
65	5,726	99,631	332,189	281,944	94,830
66	13,118	145,537	356,411	300,894	108,866
67	17,159	187,554	356,868	303,813	121,807
68	20,002	211,829	328,330	277,198	138,881
69	23,906	225,834	349,531	276,618	153,144
70	20,432	218,716	290,380	245,239	126,551
71	18,652	233,909	212,290	190,198	125,742
72	20,698	252,740	209,882	192,437	109,104
73	22,232	245,304	190,148	163,424	116,958

Table XV. (continued)

	Fiscal Year													
A/C	73	72	71	70	69	68	67	66	65	64	63	62	61	60
A-3	1.53	.71	2.09	1.33	1.93	2.45	1.51	1.10	1.00	1.70	1.90	2.10	3.60	3.60
A-4	1.44	1.20	1.40	2.30	2.10	2.11	2.37	2.30	1.80	2.50	2.20	2.20	3.40	3.50
A-5	.50	2.42	2.09	5.24	7.13	5.49	5.77	.78	7.20	3.40	5.30	6.40		
A-6	1.34	1.17	1.51	1.67	1.22	1.43	1.76	2.91	.62	1.30				
A-7	1.18	2.06	2.10	3.11	3.48	3.41	2.07							
F-4	2.34	1.72	2.58	2.52	2.42	2.67	3.17	2.70	3.20	4.40	4.71	5.20		
F-8	2.98	2.04	4.06	4.90	6.36	3.39	4.69	3.20	4.50	3.80	4.90	5.60		
E-2	1.35	.48	1.61	.49	1.25	1.00	1.17	.76	0	4.20			4.70	5.60
P-3	.08	.16	.04	0	.13	.19	.11	.10	.30	.20	.50	.50		
S-2	.16	.29	.42	.27	.23	.23	.14	.25	.60	.40	.50	.60	.60	.90
T-28	.43	.31	.47	.40	.32	.57	.49	.70	.80	.80	1.00	1.00	1.00	1.30
T-2	.26	.55	.72	.63	1.00	1.36	.57	1.10	.40	.40	.40	1.00		

Table XVI. Accident Rates.

This data was taken from the one liners by model aircraft for FY 70. The accidents are not in chronological order. The accident numbers are arbitrary. The day column is the day each accident occurred during the year. Since only the sums of the waiting times (i.e., days of the accidents) were used in the statistical tests, the actual accident-day match-up is not of significance. This format applies to Tables XVIII and XIX also.

Accident	Day	Accident	Day	Accident	Day	Accident	Day
1	273	31	340	61	68	91	42
2	57	32	213	62	316	92	1
3	49	33	258	63	43	93	123
4	22	34	185	64	155	94	356
5	249	35	148	65	41	95	34
6	220	36	170	66	181	96	23
7	136	37	164	67	332	97	253
8	222	38	128	68	279	98	65
9	188	39	206	69	262	99	288
10	73	40	229	70	22	100	239
11	119	41	341	71	184	101	48
12	127	42	142	72	180	102	232
13	73	43	291	73	129	103	354
14	208	44	107	74	331	104	361
15	182	45	365	75	299	105	260
16	330	46	223	76	227	106	160
17	204	47	226	77	185	107	189
18	213	48	41	78	265	108	64
19	174	49	277	79	228	109	60
20	198	50	302	80	244	110	114
21	309	51	196	81	323	111	323
22	174	52	247	82	93	112	4
23	172	53	4	83	297	113	101
24	363	54	211	84	234	114	264
25	58	55	56	85	107	115	164
26	293	56	193	86	19	116	175
27	8	57	231	87	294	117	320
28	330	58	87	88	241	118	122
29	127	59	228	89	230	119	64
30	158	60	159	90	48	120	212

Table XVII. FY 70, All Accident Waiting Times.

Accident	Day
121	65
122	150
123	167
124	99
125	320
126	14
127	176
128	215
129	225
130	52
131	128
132	58
133	318
134	289
135	37
136	68
137	61
138	317
139	248
140	202
141	153
142	203
143	78
144	231
145	92
146	321
147	83
148	161
149	76
150	315
151	361
152	163
153	177
154	100
155	192
156	353
157	295
158	110
159	130
160	167
161	176
162	45
163	131
164	170
165	156
166	192
167	305
168	146
169	276
170	82
171	11
172	207
173	217
174	212
175	363
176	76
177	227
178	136
179	164
180	180
181	304
182	248
183	100
184	257
185	49
186	351
187	136
188	297
189	177
190	84
191	44
192	189
193	344
194	263
195	225
196	20
197	302
198	138
199	56
200	280
201	188
202	144
203	39
204	96
205	293
206	185
207	49
208	80
209	182
210	311
211	263
212	79
213	173
214	315
215	238
216	86
217	218
218	115
219	236
220	246
221	141
222	296
223	11
224	69
225	38
226	169
227	171
228	328
229	151
230	298
231	69
232	162
233	354
234	85
235	81
236	184
237	160
238	84
239	222
240	164
241	69
242	68
243	149
244	188
245	78
246	111
247	193
248	52
249	121
250	9
251	350
252	271
253	143
254	333
255	327
256	215
257	300
258	136
259	225
260	226
261	67
262	185
263	166
264	156
265	51
266	34
267	169
268	129
269	256
270	357
271	129
272	352
273	113
274	37
275	283
276	102
277	200
278	162
279	4
280	69
281	9
282	71
283	63
284	351
285	336
286	214
287	218
288	201
289	215
290	177
291	169
292	298
293	250
294	147
295	239
296	76
297	253
298	128
299	64
300	218
301	274
302	310
303	307
304	72
305	339
306	280
307	259
308	58
309	85
310	226
311	349
312	338
313	129
314	259
315	104
316	266
317	276
318	331
319	73
320	201
321	177
322	9
323	128
324	288

Accident	Day	Accident	Day	Accident	Day	Accident	Day
325	196	355	167	383	152	411	134
326	307	356	107	384	67	412	13
327	357	357	350	385	39	413	184
328	211	358	149	386	97	414	226
329	17	359	58	387	255	415	175
330	164	360	64	388	86	416	114
331	134	361	111	389	306	417	256
332	41	362	93	390	186	418	289
333	163	363	56	391	245	419	211
334	207	364	192	392	125	420	270
335	47	365	77	393	40	421	154
336	153	366	238	394	176	422	304
337	117	367	69	395	127	423	36
338	239	368	292	396	51	424	193
339	224	369	198	397	251	425	83
340	249	370	128	398	269	426	326
341	223	371	214	399	244	427	174
342	29	372	224	400	184	428	195
343	40	373	91	401	322	429	341
344	248	374	87	402	285	430	156
345	52	375	186	403	63	431	132
346	126	376	363	404	323	432	161
347	192	377	223	405	210	433	76
348	262	378	11	406	291	434	284
349	339	379	48	407	118	435	328
350	58	380	224	408	212	436	315
351	262	381	70	409	329	437	204
352	11	382	117	410	57	438	222
353	324					439	242
354	137						

A-7 Accidents
(FY 72)

Accident	Day	Accident	Day
1	44	23	36
2	306	24	316
3	168	25	146
4	252	26	18
5	141	27	336
6	30	28	340
7	266	29	337
8	169	30	83
9	51	31	79
10	67	32	26
11	261	33	251
12	105	34	309
13	169	35	200
14	293	36	233
15	171	37	67
16	67	38	31
17	159	39	175
18	274	40	281
19	22	41	113
20	42	42	66
21	288	43	137
22	286		

Prop Accidents (FY 72)
(C1,C2,E1,E2,P3,C130,S2,P2)

Accident	Day	Accident	Day
1	17	11	147
2	236	12	155
3	347	13	347
4	29	14	252
5	15	15	322
6	344	16	68
7	339	17	320
8	211	18	42
9	203	19	81
10	340		

Table XVIII. A-7 and Prop Accident Waiting Times.

A-7 Landing Accidents
(FY 70,71,72)

Accident	Day	Converted to 3 Year Base	Accident	Day	Converted to 3 Year Base
1	67	797	16	198	563
2	159	889	17	307	672
3	42	772	18	175	175
4	322	1052	19	14	14
5	210	940	20	176	176
6	233	963	21	235	235
7	281	1011	22	52	52
8	137	867	23	289	289
9	305	670	24	68	68
10	317	682	25	202	202
11	195	560	26	321	321
12	294	659	27	163	163
13	36	401	28	353	353
14	97	462	29	130	130
15	48	413	30	45	45

A-7 Inflight Accidents
(FY 71,72)

Accident	Day	Converted to 2 Year Base	Accident	Day	Converted to 2 Year Base
1	141	506	18	161	161
2	266	631	19	166	166
3	105	470	20	342	342
4	179	544	21	323	323
5	171	536	22	25	25
6	67	432	23	108	108
7	274	639	24	364	364
8	146	511	25	339	339
9	336	701	26	171	171
10	337	702	27	77	77
11	83	448	28	226	226
12	251	616	29	127	127
13	309	674	30	338	338
14	67	432	31	167	167
15	31	396	32	321	321
16	175	540	33	49	49
17	113	478			

Table XIX. A-7 Landing and Inflight Accident Waiting Times.

By Sources (all in minutes)

Aircraft	(Average Sortie Time in Hours)	Takeoff	Climb	Inflight	Descent	Land
A-3	(2.3)					
Analyst						
VAQ-33		1.5	25	92.5	15	4
VAQ-130		.7	10	108.3	14	5
VAQ-308		1.0	9	108.0	15	4
A-4	(1.6)					
Analyst		1.0	10	76.0	6	3
VA-127		1.0	8	77.0	5	5
VA-45		1.0	6	78.0	6	5
VMA-331		.5	6	74.5	10	5
A-5	(1.8)					
Analyst		3.0	12	79.0	10	4
RVAH-6		1.5	12	76.5	12	6
RVAH-5		2.0	10	82.0	12	2
RECONWING 1		1.0	10	84.0	8	5
A-6	(1.9)					
Analyst		1.0	6	96.0	8	3
VA-42		1.0	3	100.0	5	5
VX-5		2.0	3	98.0	5	6
VA-75		2.0	7	96.0	5	4
VA-85			10		10	
A-7	(1.7)					
Analyst		1.0	9	78.0	10	4
VA-122		2.0	7	78.0	10	5
VA-147		1.5	5.5	82.0	10	3
VA-174		1.0	12	80.0	12	6
F-4	(1.5)					
Analyst		1.0	12	64.0	10	3
VF-11		1.0	3	73.0	8	5
VF-74		.5	3	73.5	9	4
VF-84		1.0	3	75.5	7	3.5
F-8	(1.6)					
Analyst		2.0	10	71.0	10	3
VF-301		2.0	10	69.0	13	2
VF-202		.5	10	73.5	10	2
VFP-63		.75	4.5	83.75	4	3

Table XX. Time Estimates.

Table XX continued

Aircraft	(Average Sortie Time in Hours)	Takeoff	Climb	Inflight	Descent	Land
E-2	(2.6)					
Analyst		1.0	16	120.0	16	3
RVAW-120		1.0	19	115.0	15	6
VAW-113		1.0	18	122.0	12	3
VAW-123		3.0	20	117.0	6	10
P-3	(5.1)					
Analyst		1.0	15	275.0	14	2
VP-31		1.5	15	265.5	15	9
VP-40		3.0	15	266.0	15	7
VP-16		1.0	18	269.0	15	3
VP-8						4
VP-49						3.5
S-2	(2.8)					
Analyst		1.2	6	153.6	6	1.2
VT-28		1.8	6	148.2	6	6
VS-30		.75	4	146.25	11	6
VS-72		.75	5	150.25	8	4
T-28	(1.3)					
Analyst		1.0	5	74.0	5	5
VT-2		.25	5	59.75	4	3
VT-6		1.0	6	41.00	11	19
VT-3		1.0	5	57.0	10	5
T-2	(1.3)					
Analyst		1.0	8	55.0	5	3
VT-9		2.0	8	37.0	5	20
VT-23		2.0	4	62.0	6	4
VT-26		1.0	4	41.0	7	15

(TOTAL HOURS 261,919) A-3 (ACCIDENT RATE 1.41)

	Takeoff	Inflight	Transition	Landing
I. Hours in Phase	2,095.35	196,098.75	55,526.82	8,198.06
II. # Accidents in Phase	5	9	3	20
III. Risk Rate	23.86	.46	.54	24.40
(1,747,814) A-4 (1.68)				
I.	15,905.11	1,390,560.81	259,375.59	81,972.47
II.	62	108	41	83
III.	38.98	.78	1.58	10.13
(73,812) A-5 (3.93)				
I.	1,284.33	54,930.89	14,688.59	2,900.81
II.	4	9	2	14
III.	31.14	1.64	1.36	48.26
(513,601) A-6 (1.38)				
I.	6,728.17	429,627.93	56,958.35	20,287.24
II.	14	40	11	6
III.	20.81	.93	1.93	2.96
(908,149) A-7 (2.17)				
I.	12,260.01	685,924.94	169,823.86	40,049.37
II.	38	84	31	44
III.	30.99	1.22	1.82	10.99

Computation of Risk Rates, FY 69 Through FY 73.

Computation of Risk Rates continued

(1,016,794) F-4 (2.21)

I.	9,862.90	807,944.51	155,366.12	43,620.46
II.	40	103	23	59
III.	40.56	1.27	1.48	13.52

(428,616) F-8 (4.22)

I.	6,086.35	331,577.34	79,765.44	11,144.02
II.	15	69	21	76
III.	24.64	2.08	2.63	68.20

(105,920) E-2 (1.04)

I.	1,016.83	80,456.83	20,707.36	3,728.38
II.	3	1	2	5
III.	29.50	.12	.96	13.41

(1,176,553) P-3 (.07)

I.	6,118.07	1,034,896.02	117,302.33	18,236.57
II.	1	4	1	2
III.	1.63	.04	.08	1.09

(1,252,231) S-2 (.27)

I.	8,389.95	1,114,861.26	96,922.68	32,057.11
II.	6	6	5	17
III.	7.15	.54	.51	5.30

Computation of Risk Rates continued

(631,449) T-2 (.67)

I.	12,124	439,270	95,103	84,499
II.	8	22	6	6
III.	6.60	.50	.63	.71

(1,067,916) T-28 (.35)

I.	10,999	772,744	174,604	109,568
II.	7	15	4	11
III.	6.36	.19	.23	1.00

A-3

FY	Takeoff	Inflight	Transition	Landing	Total
60	2	5	4	10	21
61	5	3	1	19	28
62	2	3	2	9	16
63	1	4	1	10	16
64	1	3	2	8	14
65	2	3	1	1	7
66	2	0	0	0	7
67	2	1	3	4	10
68	3	2	3	8	16
69	1	2	2	5	10
70	1	2	0	5	8
71	1	3	0	6	10
72	0	0	1	2	3
73	2	2	0	2	6
A-4					
60	5	22	12	18	57
61	13	25	7	30	75
62	10	24	10	27	71
63	5	21	7	38	71
64	13	32	13	92	87
65	7	27	7	28	69
66	19	41	3	38	101
67	14	34	13	40	101
68	17	40	12	29	98
69	22	32	8	30	92
70	19	29	14	19	81
71	8	18	7	12	45
72	5	13	6	8	32
73	8	16	6	14	44
A-5					
61	0	0	1	1	2
62	1	0	0	2	3
63	2	1	0	3	6
64	1	4	0	2	7
65	1	5	1	4	11
66	1	1	0	12	14
67	1	1	0	7	9
68	1	3	1	3	8
69	1	3	1	6	11
70	1	3	0	4	8
71	1	0	0	3	4
72	0	3	1	1	5
73	1	0	0	0	1

Table XXI. Accident Breakdown, FY 69 Through FY 73.

Table XXI. continued

A-6

FY	Takeoff	Inflight	Transition	Landing	Total
64	0	0	1	0	1
65	0	1	0	0	1
66	2	6	0	1	9
67	3	3	0	2	8
68	0	4	5	0	9
69	2	8	2	0	12
70	2	11	3	0	16
71	3	9	2	2	16
72	3	5	3	1	12
73	4	7	1	3	15
A-7					
66	0	1	0	0	1
67	0	3	0	0	3
68	3	12	1	3	19
69	6	20	7	0	42
70	9	21	5	14	49
71	8	16	6	9	39
72	6	17	10	8	41
73	9	10	3	4	26
E-2					
64	1	0	0	0	1
65	0	0	0	0	0
66	0	0	0	0	0
67	0	0	0	1	1
68	0	0	0	2	2
69	1	0	0	2	3
70	1	0	0	0	1
71	1	0	0	2	3
72	0	0	1	0	1
73	0	1	1	1	3
F-4					
60	0	1	0	0	1
61	1	1	1	1	4
62	0	6	1	4	11
63	4	6	1	12	23
64	4	6	7	24	41
65	9	10	5	11	35
66	6	16	4	16	42
67	12	26	3	19	60
68	12	20	7	16	55
69	9	25	3	14	51
70	8	26	4	12	50
71	8	21	9	10	48

Table XXI. continued

FY	Takeoff	Inflight	Transition	Landing	Total
			F-4 continued		
72	6	15	2	10	33
73	9	16	5	13	43
			F-8		
60	11	25	12	24	72
61	10	21	11	35	77
62	9	35	13	39	96
63	11	18	17	46	92
64	12	24	8	36	80
65	13	20	8	55	96
66	5	14	12	30	61
67	12	26	5	35	78
68	6	17	4	20	47
69	8	27	6	28	69
70	1	23	5	21	50
71	3	8	5	16	32
72	2	3	2	5	12
73	1	8	3	6	18
			P-3		
63	0	1	0	0	1
64	0	0	0	1	1
65	0	1	0	2	3
66	1	1	0	0	2
67	0	0	0	0	0
68	0	3	0	1	4
69	1	1	0	1	3
70	0	0	0	0	0
71	0	1	0	0	1
72	0	2	1	0	3
73	0	0	0	1	1
			S-2		
60	3	4	3	11	21
61	4	5	2	4	15
62	0	4	1	15	20
63	1	4	1	5	11
64	1	5	2	7	15
65	6	4	2	6	18
66	2	4	0	3	9
67	2	2	1	2	7
68	3	2	2	4	11
69	2	1	1	4	8
70	3	0	1	3	7
71	1	2	2	4	9

Table XXI. continued

FY	Takeoff	Inflight	Transition	Landing	Total
S-2 continued					
72	0	3	0	3	6
73	0	0	1	2	3
T-2					
60	0	2	1	1	4
61	3	1	2	1	7
62	1	4	2	1	8
63	0	1	1	2	4
64	0	2	0	1	3
65	0	2	1	1	4
66	2	5	3	2	12
67	0	3	1	3	7
68	1	8	1	7	17
69	3	9	3	2	17
70	1	3	1	3	8
71	2	5	2	0	9
72	1	3	0	1	5
73	1	2	0	0	3
T-28					
60	10	7	9	7	33
61	9	7	3	8	27
62	3	9	4	10	26
63	6	9	4	7	26
64	8	6	2	6	22
65	4	7	4	5	20
66	5	2	3	10	20
67	3	6	1	4	14
68	1	7	3	4	15
69	2	2	0	3	7
70	1	6	0	3	10
71	3	3	2	1	9
72	1	3	1	0	5
73	0	1	1	4	6

APPENDIX F: A DISCUSSION OF DATA COLLECTION

All aircraft accident data available at Naval Safety Center was stored on magnetic computer tape. It was processed through a Honeywell H-1200 computer which has a 114,000 core storage capability. Available data consisted of all information related to each Naval aircraft accident as required by Opnav instruction 3750.6. The IFARS (individual flight activity reporting system) data, which was also available, consisted of all flight hours of Navy pilots and flight officers. IFARS data also gave all Navy aircraft flight hours from 1969 to the present time.

The primary form of the accident data used in this study was an abbreviated format called a "one liner". This consisted of a one line computer printout of various pieces of data concerning a specific accident. There were various forms of one liners used at Safety Center. The aircraft analysts used a one liner with the date of the accident, type aircraft involved, injuries, assigned causes, and pilot's name and personal data. There were also formats which contained only information on the type of aircraft involved, its power plant, and any mechanical causes of the accident. The primary format of the accident data that was used in the analysis of risk was a statistical form of one liner called a "Haines one liner". This presented, in coded format, the date of the accident, type of aircraft,

reporting custodian, injuries and damage, location, phase of flight, causes, and many other pieces of significant data. A sample of a Haines one liner is given on the following page, along with an interpretation of the data it presents. If, instead of a coded presentation of the accident data, a word description was desired, four types of descriptions were available. Type 1 was a general mishap narrative; Type 2 a Bio-Med narrative; Type 3 a safety and survival narrative, and; Type 4 a psychological narrative. All narratives were drawn from the basic data stored on an accident, and they are essentially word descriptions of some of the one liners.

Once preliminary study had been done on the data available, a collection procedure was set up to obtain the desired data. This collection was done by a computer sort of specific data fields in the Haines one liner. Since accidents were to be investigated by risk areas, the sort program used the phase of flight code as its primary sort criteria. In cases where ship/shore operations had to be differentiated, the type operations data field was interrogated. On the following page the actual sort program used is shown in flow chart form.

It should be mentioned that not all accidents in the safety center files were used in this study. All accidents that did not conform to one of the risk areas studied were excluded from the computer sort, and thus excluded from further analysis. These deleted accidents included static

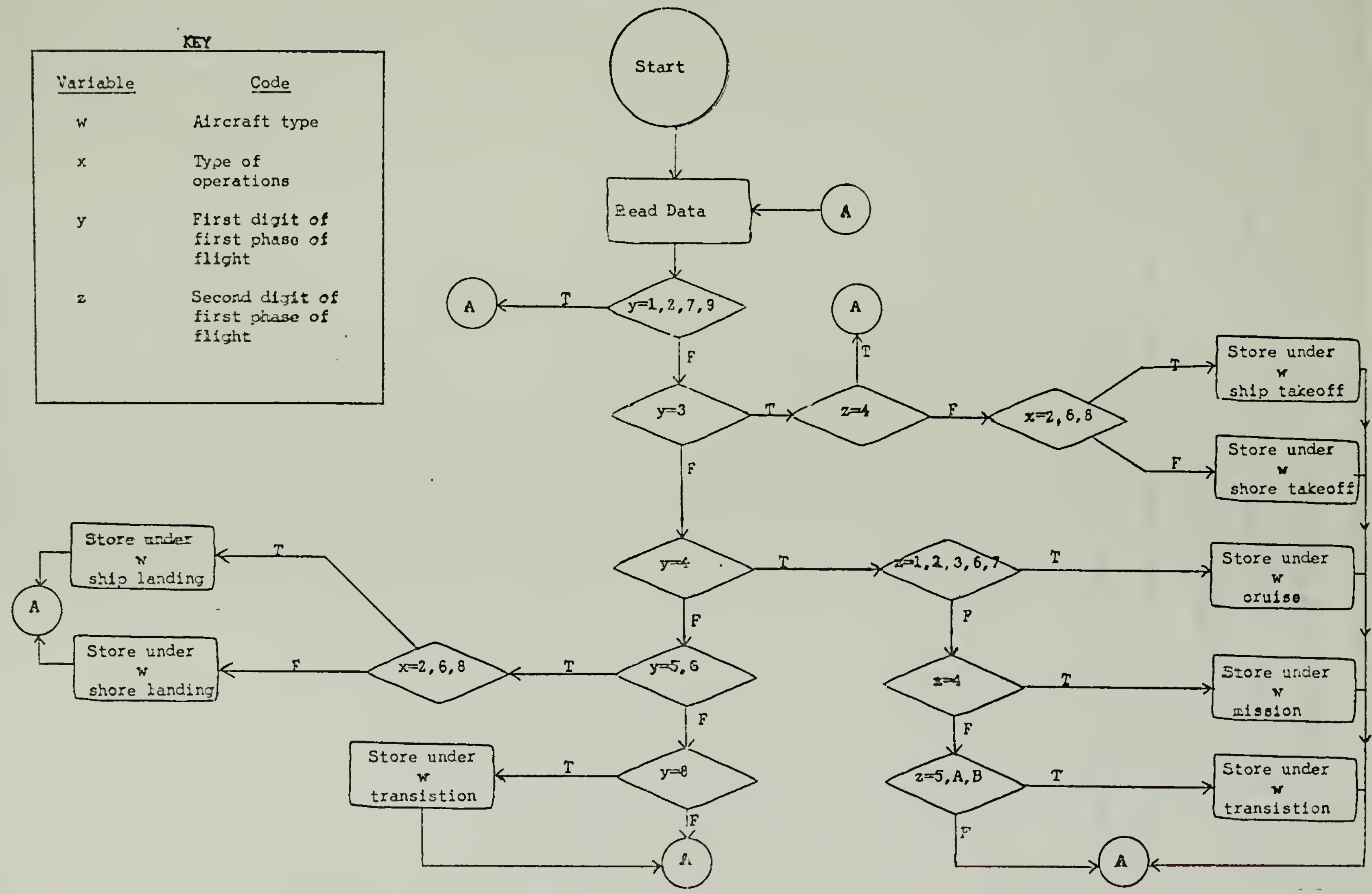
EXAMPLE OF HAINES ONE LINER

```
Field  1  2  3      4     5     6  7  8  9  10      11     12    13     14     15   16   17  18 . 19 20 21 22
   700811 F004J 155783 CCGG A07 63 23 2 31A2 B2IWAKU P033 CL537 C4537 4312 XGB3 E2 I3998          M
```

Field	Meaning*: Example
1	Identification Number of accident: This accident occurred on 11 Aug 70. It was the first accident of the day, and only one aircraft was involved.
2	Direct Enemy Action/Don't Count Accident: Not Applicable.
3	Aircraft Type: F4J
4	Bureau Number: 155783
5	Damage/Injury: given in sequence of; in accident, to this aircraft. In this accident, substantial damage, no injuries.
6	Reporting Custodian: VMFA 232
7	Squadron Class: VMFA (Marine Fighter)
8	Major Command: FMFPAC
9	Condition: Daytime
10	Flight Purpose Code/Type Operations: unit training/shore based.
11.	Location of Accident: Iwakuni, Japan
12	First Cause/Phase of Operations: System malfunction/aborted takeoff.
13	Second Cause/Phase of Operations: Landing gear collapse/roll out from landing.
14	Third Cause/Phase of Operations: Aircraft struck by its own components/roll out from landing.
15	Contributing Causes: Material design, system failure, pilot, other personnel.
16	Pilot Cause Factors: Judgement error, performed improperly.
17	Other personnel factors: RIO
18	First Involved Material Component: instrument, air data computer.
19	Second Involved Material Component: Not Applicable.
20	Third Involved Material Component: Not Applicable.
21	Design Cause Factors: Not Applicable
22	Special Data: Violation or lack of NATOPS, SO

*Complete code interpretation is found in Manual of Code Classification for Navy Aircraft Accident, Incident, and Ground Accident Reporting, Records Division, Records and Data Processing Department, Naval Safety Center, Norfolk, Va., 1 July 1972.

ACCIDENT SORTING FLOW CHART


Start
Read Data
A
y=1,2,7,9
T
F
y=3
z=4
x=2,6,8
Store under w ship takeoff
Store under w shore takeoff
y=4
z=1,2,3,6,7
Store under w cruise
z=4
Store under w mission
z=5,A,B
Store under w transistion
y=5,6
x=2,6,8
Store under w ship landing
Store under w shore landing
y=8
Store under w transistion

KEY

Variable	Code
w	Aircraft type
x	Type of operations
y	First digit of first phase of flight
z	Second digit of first phase of flight

accidents, taxi accidents, and accidents on which no information was available (coded as undetermined accidents). These accidents comprised a small proportion (1.6% over the period of primary interest) of the total number of accidents. Since their related risk areas were not significant, their deletion did not effect the risk analysis in any way.

FLIGHT PHASE SORTING CRITERIA

First Phase of flight codes are presented on the following pages. The below listed sort criteria were used to divide accidents into the four risk areas, and sub-areas.

RISK AREA		FIRST PHASE CODE
Takeoff		All 3 codes
Inflight	Inflight(cruise)	412,413,415,416,417,41,46, 43,470,472,473,476,477,478, 479,47A,47B
	Inflight(mission)	42,44,411,414,437,43B,475
Transition		8,45,4A,4B
Landing		All 5 and 6 codes.

All codes not listed above were not classified and the associated accidents were not considered in the analysis. The breakdown by ship/shore was done by a separate type operation code.[7] A copy of the phase of operations criteria from the code manual follows:

---

[7] Manual of Code Classification for Navy Aircraft Accident, Incident, and Ground Accident Reporting, Records Division, Naval Safety Center, Norfolk, Virginia, 1 July 1972.

PHASE OF OPERATION

PRIMARY PHASE OF OPERATION - Card Columns 24-36 Card No. 130

1ST PHASE OF OPERATION - Card Columns 29-31 Card No. 130

2ND PHASE OF OPERATION - Card Columns 34-36 Card No. 130

3RD PHASE OF OPERATION - Card Columns 39-41 Card No. 130

PRIMARY PHASE OF OPERATION IS THAT PHASE CODE WHICH COMPLEMENTS THE PRIMARY ACCIDENT TYPE CODE AND MUST MATCH ONE OF THE THREE PHASE CODES WHICH ARE CODED IN SEQUENCE OF EVENTS. THIS CODE WILL BE USED PRIMARILY FOR STATISTICAL PRESENTATIONS.

CODES

1 STATIC - ENGINE(S) RUNNING WITH AIRCRAFT NOT IN MOTION

CODES	
1	ENGAGEMENT (HELOS)
2	DISENGAGEMENT (HELOS)
3	PRIOR TO LEAVING CHOCKS
4	PRIOR TO TAKEOFF ATER LEAVING CHOCKS
5	AFTER COMPLETION OF FLIGHT (PRIOR TO FINAL CHOCKING)
6	AFTER COMPLETION OF FLIGHT (AFTER FINAL CHOCKING)
7	ENGAGING/DISENGAGING OF MOORING MAST/LTA
8	LAUNCHING OPERATIONS (SEAPLANES)
9	BEACHING OPERATIONS (SEAPLANES)
0	ENGINE STARTING
A	UNINTENTIONAL MOVEMENT OF AIRCRAFT PRIOR TO TAXI
B	ON CATAPULT BUT DID NOT TAKEOFF

CODES	
1	REFUELING

PHASE OF OPERATION (CONTINUED)

CODES

2 TAXIING - ANY TIME THE AIRCRAFT IS IN MOTION ON THE GROUND OR WATER UNDER POWER

CODES

1 TO TAKE OFF
2 FROM LANDING
3 WITHIN OTHER AREAS

3 TAKE OFF - BEGINS WITH THE INSTANT THE AIRCRAFT MOVES FORWARD (TRANSITION FROM HOVER TO FORWARD FLIGHT PRIOR TO TRANSITIONAL LIFT FOR HELOS) ON THE TAKE OFF RUN OR CATAPULT. THIS PHASE IS TERMINATED WHEN THE AIRCRAFT ATTAINS ITS CLIMB SCHEDULE. A BOLTER IS NOT TO BE INCLUDED IN THIS PHASE.

CODES

1 RUN, FROM TIME TAKEOFF POWER IS ADDED AND THE AIRCRAFT IS SET IN MOTION (MOVING) WITH THE INTENT OF BECOMING AIRBORNE. FROM BEGINNING OF RUN UNTIL AIRCRAFT LEAVES THE RUNWAY.

2 CATAPULT

3 CLIMB - REFERS TO MISHAPS OCCURRING FROM THE TIME THE AIRCRAFT BREAKS GROUND UNTIL IT IS CLEANED UP AND BEGINS CLIMB SCHEDULE.

4

5 HOVER

6 HOVER TRANSITION TO FORWARD FLIGHT

CODES

1 TOUCH AND GO LANDING OR FMLP/FCLP

2 FORMATION

3 TAKE OFF ABORTED UTILIZING FIELD ARRESTING GEAR

4 ACTUAL OR SIMULATED INSTRUMENT TAKE OFF

5 AIRCRAFT LAUNCHED FROM CATAPULT

6

7 AEROBATICS

8 PRIOR TO DECISION SPEED

9 PRIOR TO REFUSAL SPEED

A PRIOR TO ROTATION SPEED

PHASE OF OPERATION (CONTINUED)

CODES	
B	ABORT
Y	FOLLOWED BY AUTOROTATION

CODES

4 IN FLIGHT - INCLUDES PERIOD STARTING FROM THE COMMENCEMENT OF THE CLIMBOUT PHASE UNTIL THE TIME WHEN LANDING PROCEDURES ARE BEGUN AND LANDING CHECK OFF LIST IS EMPLOYED.

CODES		CODES	
1	NORMAL - INCLUDES ALL FLIGHTS INVOLVING MODERATE CHANGES OF SPEED, DIRECTION AND ALTITUDE.	1	
		2	TRANSIENT - HIGH ALTITUDE
		3	TRANSIENT - LOW ALTITUDE
		4	PATROL/SURVEILLANCE
		5	LOITER
		6	EXTERNAL SLING/HOIST (NOT HOVERING)
		7	OVERWATER/OVERLAND NAVIGATION
		8	TRANSITION FROM HOVER TO NORMAL FLIGHT OR FROM NORMAL FLIGHT TO A HOVER WITH AN EXTERNAL LOAD
		Y	FOLLOWED BY AUTOROTATION
2	AEROBATICS - INCLUDES INTENTIONAL MANEUVERS OF ABRUPT CHANGE IN DIRECTION SPEED AND ALTITUDE.		

PHASE OF OPERATION (CONTINUED)

CODES				
4	CODES		CODES	
	3	FORMATION	1	RENDEZVOUS
			2	CROSS OVER/CROSS UNDER
			3	FORMATION DIVE
			4	NORMAL FORMATION
			5	TURNING
			6	OTHER
			7	TAIL CHASE
			8	LEAD CHANGE
			9	PARADE FORMATION
			0	UNDETERMINED
			A	BREAK-UP (DO NOT USE FOR FORMATION BREAK-UP FOR LANDING)
			B	AEROBATICS
			Y	FOLLOWED BY AUTO-ROTATION
	4	OFFENSIVE MANEUVERS	1	AERIAL GUNNERY
			2	STRAFING RUN
			3	ROCKET RUN
			4	GLIDE/DIVE BOMBING
			5	DEFENSIVE WEAVE
			6	OTHER
			7	COMBAT TACTICS
			8	ASW TACTICS (JULIE, MAD, ETC.)

PHASE OF OPERATION (CONTINUED)

CODES	CODES		CODES	
4	4	OFFENSIVE MANEUVERS	9	LOFT MANEUVERS
			0	AIR TO AIR INTERCEPT
			A	HIGH ALTITUDE BOMBING
			B	MISSILE RUN
			C	LAY DOWN DELIVERY/ NAPALM
			D	LOW LEVEL TARGET RUN-IN
			E	MINE COUNTER MEASURES
			F	HELP COVER
	5	VER BREAK - INCLUDES MISHAPS OCCURRING FROM THE TIME THE AIRCRAFT ENTERS THE SLOT FOR BREAK INTO THE LANDING PATTERN THROUGH THE DOWNWIND LEG UP TO THE 180 DEGREE POSITION ON FIRST APPROACH ONLY. OTHERWISE USE CODE 4B.	1	TOUCH AND GO LANDINGS
			2	FORMATION
			3	
			Y	FOLLOWED BY AUTOROTATION
	6	HOLDING PATTERN	1	
			Y	FOLLOWED BY AUTOROTATION
	7	OTHER MANEUVERS	1	
			2	LOW LEVEL NAVIGATION
			3	UNUSUAL ALTITUDE
			4	AIR TAXI (HELO)
			5	SEARCH AND RESCUE
			6	ILLEGAL MANEUVERS/ UNAUTHORIZED

PHASE OF OPERATION (CONTINUED)

CODES

4	CODES		CODES	
	7	OTHER MANEUVERS	7	SUPERSONIC FLIGHT
			8	REFUELING
			9	UTILITY/SUPPORT (PLANE GUARD)
			0	OTHER
			A	TRANSONIC FLIGHT (.89 to .99 MACH)
			B	TEST FLIGHT
			Y	FOLLOWED BY AUTO-ROTATION
	8	UNDETERMINED		
	9	HOVER (HELOS)	1	ASW
			2	EXTERNAL SLING
			3	EXTERNAL HOIST
			4	ENGINE RUN IN
			9	RAPELLING
			0	TROOP DEBARKATION
			Y	FOLLOWED BY AUTO-ROTATION
	A	CLIMB OUT - INCLUDES MISHAPS OCCURRING FROM TIME THE AIRCRAFT IS CLEANED UP AND ATTAINED CLIMB SCHEDULE UNTIL THE AIRCRAFT HAS REACHED THE DESIRED ALTITUDE FOR COMMENCEMENT OF ASSIGNED MISSION	1	TOUCH AND GO LANDINGS
			2	FORMATION
			3	
			4	ACTUAL OR SIMULATED INSTRUMENT TAKE OFF
			Y	FOLLOWED BY AUTO-ROTATION

PHASE OF OPERATION (CONTINUED)

CODES		
4	CODES	CODES
	B LANDING PATTERN	1 UPWIND 2 TURNING CROSSWIND 3 DOWNWIND 4 TURNING BASE ON CCA/GCA OR IFR APPROACHES Y FOLLOWED BY AUTO-ROTATION
5	LANDING - INCLUDES THAT PERIOD FROM THE TIME THE PILOT PASSES THE 180 DEGREE POSITION DURING A CIRCLING APPROACH; OR WHILE ON FINAL DURING A STRAIGHT-IN APPROACH TO THE END OF THE LANDING ROLL ON THE RUNWAY; OR THE TIME WHEN THE AIRCRAFT SLOWS TO TAXIING SPEED; OR THE AIRCRAFT IS BROUGHT TO STOP BY CROSS-DECK PENDANT OR BARRICADE IN CARRIER LANDING.	
	1 APPROACH - INCLUDES ACCIDENTS FROM THE 180 DEGREE POSITION (TURNING BASE) THROUGH THE FINAL AND UP TO THE TRANSITION OR LEVEL OFF/OR TOUCHDOWN. FOR HELOS IT COMMENCES WHEN FORWARD SPEED IS DECREASED TO A DESCENT SPEED APPROXIMATELY 55 TO 60 KNOTS. THIS PHASE ENDS WITH THE COMMENCEMENT OF THE FLARE.	1 TOUCH AND GO LANDING 2 FORMATION 3 MIRROR APPROACH 4 FLAMEOUT (SIMULATED) 5 FLAMEOUT (ACTUAL) 6 BOLTER, MIRROR APPROACH 7 FIELD ARRESTING GEAR
	2 LEVEL OFF AND/OR TOUCHDOWN - INCLUDES THAT PERIOD FROM THE MOMENT THE AIRCRAFT CHANGES FROM AND APPROACH ATTITUDE TO A LANDING ATTITUDE UNTIL THE MOMENT THE AIRCRAFT MAIN MOUNTS MAKES CONTACT	8 BOLTER - LSO APPROACH 0 IN FLIGHT ENGAGEMENT OF ARRESTING WIRE A TOUCH AND GO MIRROR APPROACH

PHASE OF OPERATION (CONTINUED)

CODES

5 CODES

WITH LANDING SURFACE. STALL ACCIDENTS OCCURRING DURING LEVEL OFF ARE TO BE CLASSIFIED AS LANDING ACCIDENTS. FOR HELICOPTERS IT COMMENCES WITH THE FLARE AND ENDS WHEN CONTACT WITH THE GROUND OR WATER IS MADE.

3 ROLL OUT - INCLUDES THAT PERIOD AFTER TOUCHDOWN TO A POINT IN LANDING ROLL WHERE SPEED HAS DECREASED TO A SAFE TAXIING SPEED, OR A POINT OF MAXIMUM EXTENSION OF CROSS DECK PENDANT IN CV LANDINGS. IN TOUCH AND GO LANDING PRACTICE THE ROLL IS THAT PERIOD FROM THE TIME THE AIRCRAFT TOUCHES DOWN UNTIL THE TIME PILOT APPLIES POWER FOR TAKE OFF. FOR HELICOPTERS, IT COMMENCES WITH THE CONTACT WITH THE GROUND OR WATER (TOUCH DOWN) AND ENDS WHEN THE HELICOPTER'S FORWARD SPEED IS STOPPED.

4 BOLTER

CODES	
B	FRESNEL APPROACH
C	BOLTER - FRESNEL APPROACH
D	INFLIGHT ENGAGEMENT OF ARRESTING WIRE ON MIRROR APPROACH
E	INFLIGHT ENGAGEMENT OF ARRESTING WIRE ON FRESNEL APPROACH
F	
G	MANUAL OPERATED VISUAL LANDING AID
H	MODE I (ACLS)
J	MODE II (SEMI-ACLS)
K	MODE III OR CASE III (FULL INSTRUMENT CCA APPROACH)
L	CASE I (VFR APPROACH)
M	CASE II (TACAN APPROACH TO VFR CONDITIONS)
Y	FOLLOWED BY AUTOROTATION

6 WAVE OFF - BEGINS AT THE TIME WHEN PILOT ABORTS HIS LANDING ATTEMPT (APPLICATION OF POWER) ON FINAL APPROACH AT THE DIRECTION OF THE LSO, OR OTHER LANDING DIRECTORS, OR CHOOSES TO DO SO ON HIS OWN, AND ATTEMPTS TO REGAIN SUFFICIENT AIRSPEED AND ALTITUDE TO GO AROUND.

PHASE OF OPERATION (CONTINUED)

CODES

6 CODES

1 CAUGHT WIRE ON WAVE OFF
2 HIT BARRIER OR BARRICADE ON WAVE OFF
3 INSTRUMENT APPROACH
4 BOLTER

CODES

1 TOUCH AND GO LANDINGS
2
3 MIRROR APPROACH
4 FRESNEL APPROACH
5 MANUAL OPERATED VISUAL APPROACH
6 MODE I (ACLS)
7 MODE II (SEMI-ACLS)
8 MODE III OR CASE III (FULL INSTRUMENT CCA APPROACH)
9 CASE I (VFR APPROACH)
0 CASE II (TACAN APPROACH TO VFR CONDITIONS)
Y FOLLOWED BY AUTOROTATION

7 AUTOROTATION - ACTUAL OR SIMULATED TO BE USED WHEN PILOT EFFECTS TO AUTOROTATE AND A REPORTABLE MISHAP IS INVOLVED.

6 EMERGENCY
7 SIMULATED

1 LANDING
2 POWER RECOVERY

8 LET DOWN - COMMENCES WITH A DESCENT WITH THE INTENT FOR LANDING

1 NORMAL VFR
2 FORMATION
3

1 INITIAL PART OF DESCENT
2 ARCING
3 PENETRATION TURN

PHASE OF OPERATION (CONTINUED)

CODES

8

CODES	
4	TACAN
5	VOR
6	RADAR
7	CCA
8	ADF
9	UHF/DF
0	GCA/ASR
A	GCA/PAR
B	ILS
C	AUTOMATIC
D	AIRCRAFT RADAR

CODES	
4	GATE
5	UPWIND
6	TURNING CROSSWIND
7	DOWNWIND
8	TURNING BASE
9	TRANSITION TO LANDING CONFIGURATION
0	AT MINIMUMS
A	LOW ALTITUDE MANEUVERING
B	TO HOVER
C	FINAL APPROACH (PRIOR TO MINIMUMS)

9 NOT INCIDENT TO FLIGHT

1	ENGINES RUNNING - NOT TAXIING (HELOS - ROTORS DISENGAGED/ENGAGED)
2	TAXI
3	OTHER
4	PARKED AIRCRAFT
5	TOWED AIRCRAFT BY POWERED VEHICLE
6	BEACHING (SEAPLANES)
7	STARTING ENGINES
8	PUSHED AIRCRAFT BY HANDLING CREW

1	FLIGHT DECK
2	HANGAR DECK
3	FIELD HANGAR
4	FIELD PARKING LINE
5	TURN UP AREA
6	OTHER
7	RUNWAY/TAXIWAY/END ZONE
8	UNPREPARED AREA
9	FUEL PITS
0	MOORED TO BUOY/MOORING MAST

PHASE OF OPERATION (CONTINUED)

CODES

9 CODES

- 9 PARKED AIRCRAFT DURING MAINTENANCE
- 0 PARKED AIRCRAFT ROTORS ENGAGED
- A GROUND HANDLING
- B PREFLIGHT (PRIOR TO ENGAGING ENGINES)

CODES

- A SHIP ELEVATOR
- B REFUELING/ DEFUELING

0 UNDETERMINED - THIS CODE WILL BE USED WHEN THE PHASE OF FLIGHT CANNOT BE DETERMINED FROM THE AIRCRAFT ACCIDENT PR INCIDENT REPORT

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